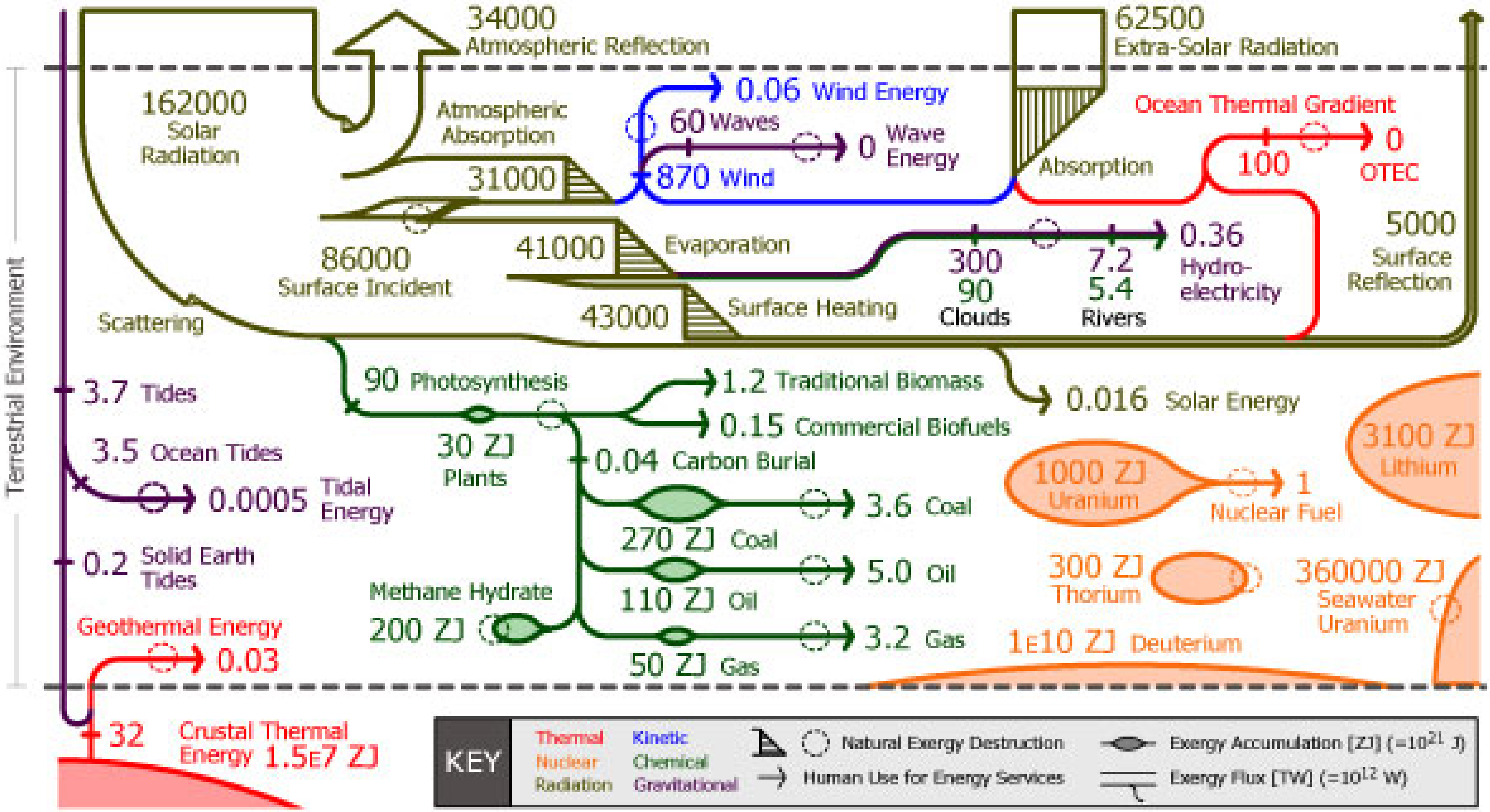
How Far Can We Reach with Emerging Generation Technologies?

Pacific Gas and Electric Company™

September 13, 2007

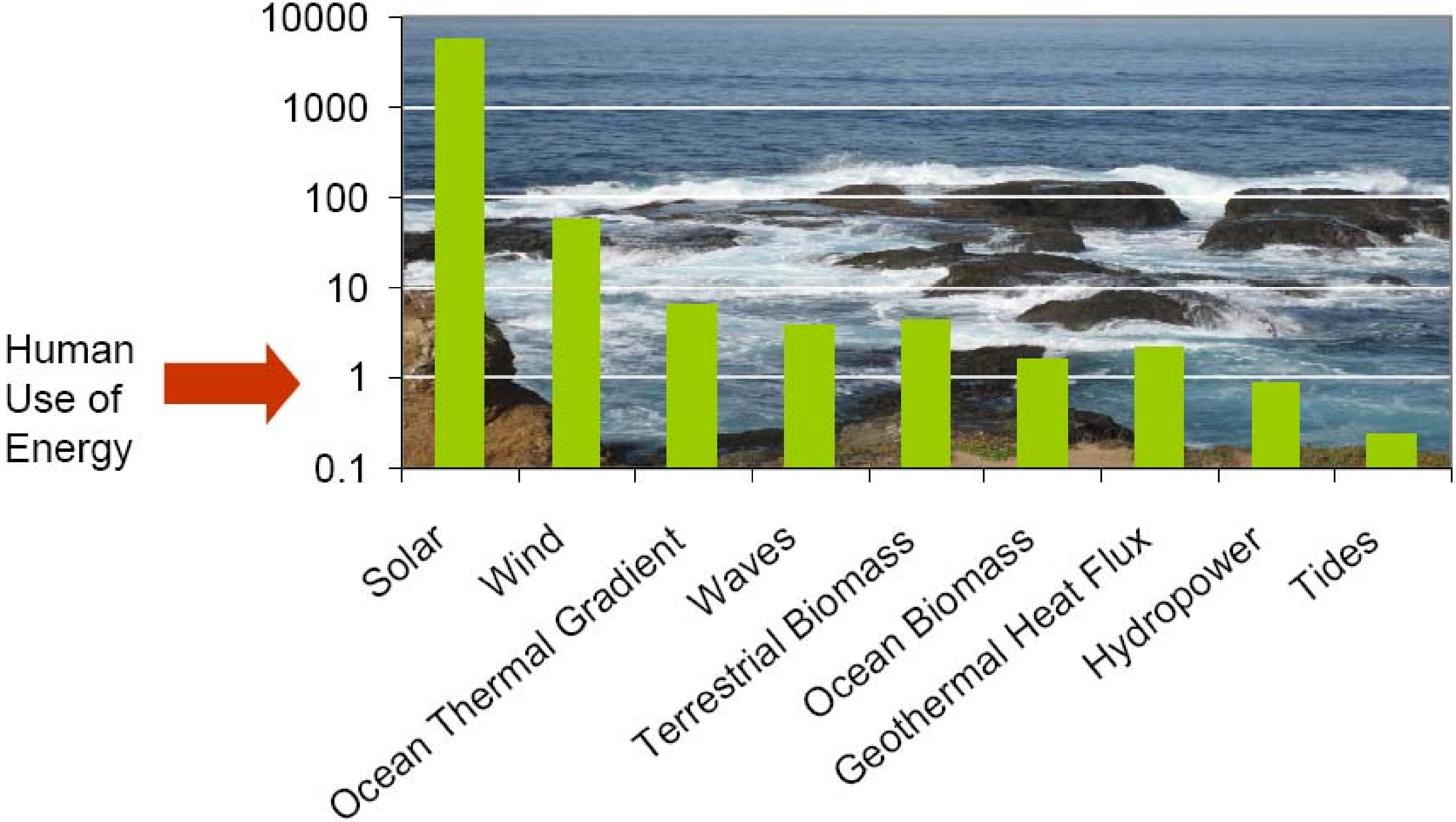
Global Exergy Flux, Reservoirs, and Destruction



Exergy is the useful portion of energy that allows us to do work and perform energy services. We gather exergy from energy-carrying substances in the natural world we call energy resources. While energy is conserved, the exergetic portion can be destroyed when it undergoes an energy conversion. This diagram summarizes the exergy reservoirs and flows in our sphere of influence including their interconnections, conversions, and eventual natural or anthropogenic destruction. Because the choice of energy resource and the method of resource utilization have environmental consequences, knowing the full range of energy options available to our growing world population and economy may assist in efforts to decouple energy use from environmental damage.

Prepared by Wes Hermann and A.J. Simon
Global Climate and Energy Project at Stanford University (http://gcep.stanford.edu)

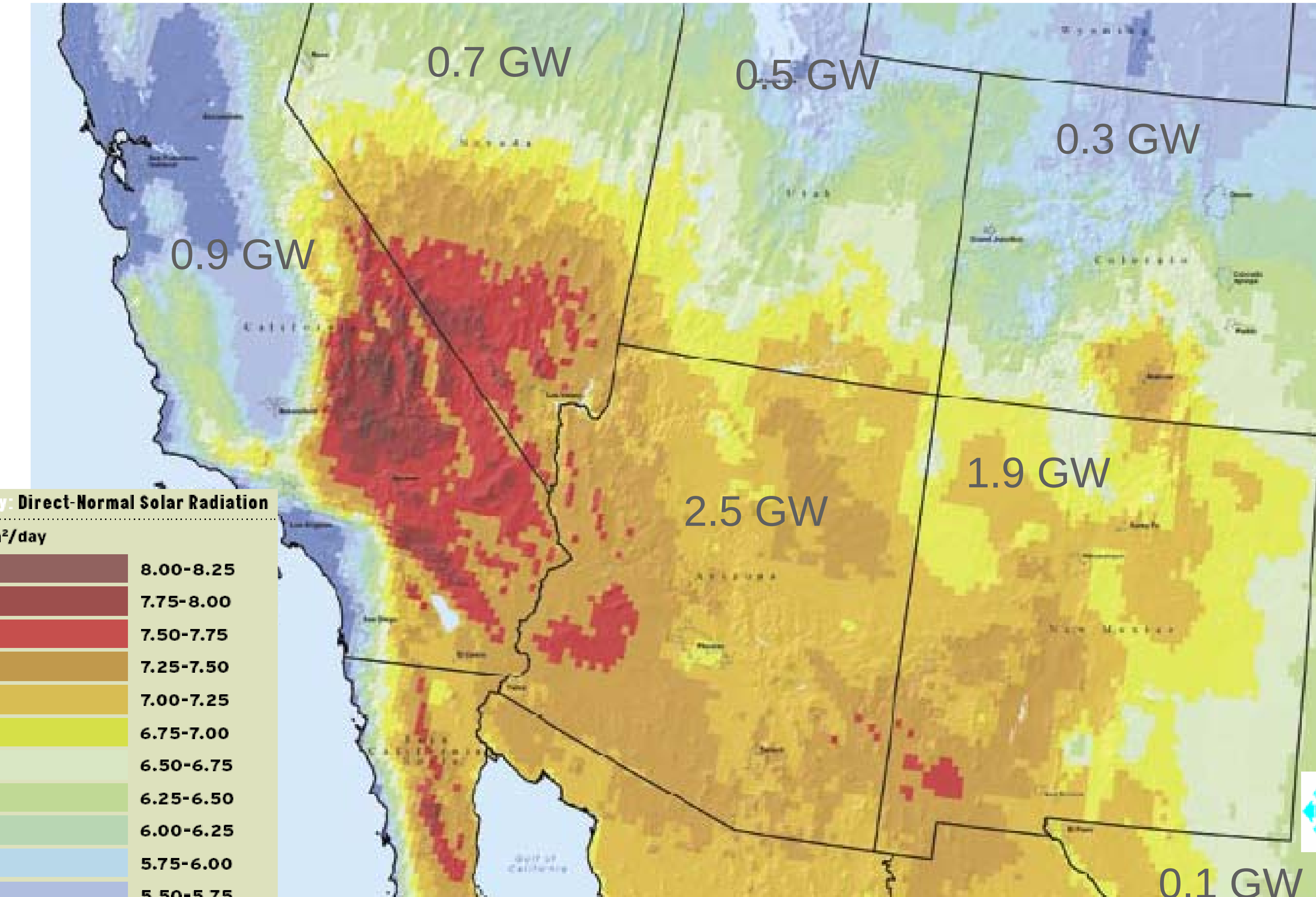
Renewable Global Exergy Flows



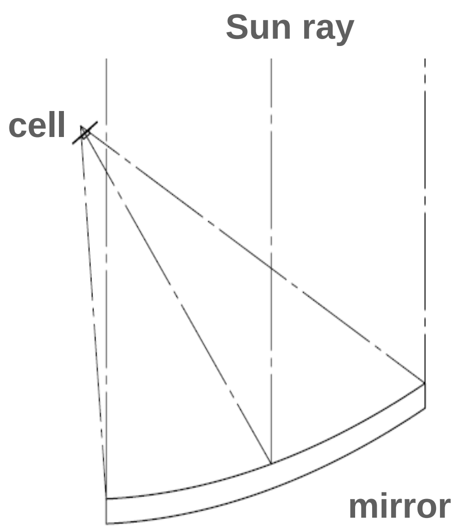
Exergy sources scaled to average consumption in 2004 (15 TW)

From Hermann, 2006: Quantifying Global Exergy Resources, Energy 31 (2006) 1349–1366

irect Normal Solar Radiation in the Southwest & Potentia enerating Capacity



Concentrating Photovoltaic



Status: Testing of Prototypes

Operation: Concentrated sunlight reflects off tracking mirrors to photovoltaic cells.

Key Advantage: Modular design and direct solar-to-electric conversion. No working fluids

Key Challenge: Getting the power cost down via efficiency improvement, technology development and manufacturing to scale.

Concentrating Thermal Trough

Compact Linea
Fresnel
Reflector
(CLFR)

Status: almost 20 years in the field

Operation: Parabolic Mirror concentrates sunlight to heat oil traveling through tube. Hot oil used to generate steam and operate a turbine connected to generator.

Key Advantage: Technology is proven and has large-scale operating history. Potential to dispatch with natural gas.

Key Challenge: Core Technology is 20+ years old and has limited improvement potential. CLFR less expensive variation.

Concentrating Thermal Tower

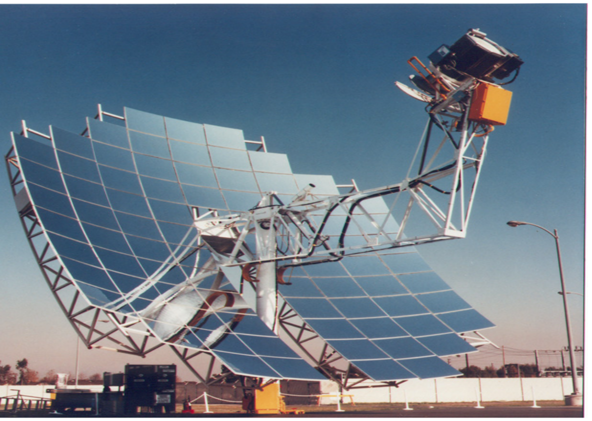
Status: Original version 20 years ago, new versions under development or construction

Operation: Mirrors focus sunlight on a central tower, where water is heated to generate steam to power steam turbine generator.

Key Advantage: Higher efficiency, simpler design, lower installation cost. Dispatchable with gas-fired boiler.

Key Challenge: No long-term operating history.

Concentrating Thermal Dish



Status: Working Prototypes (20yrs)

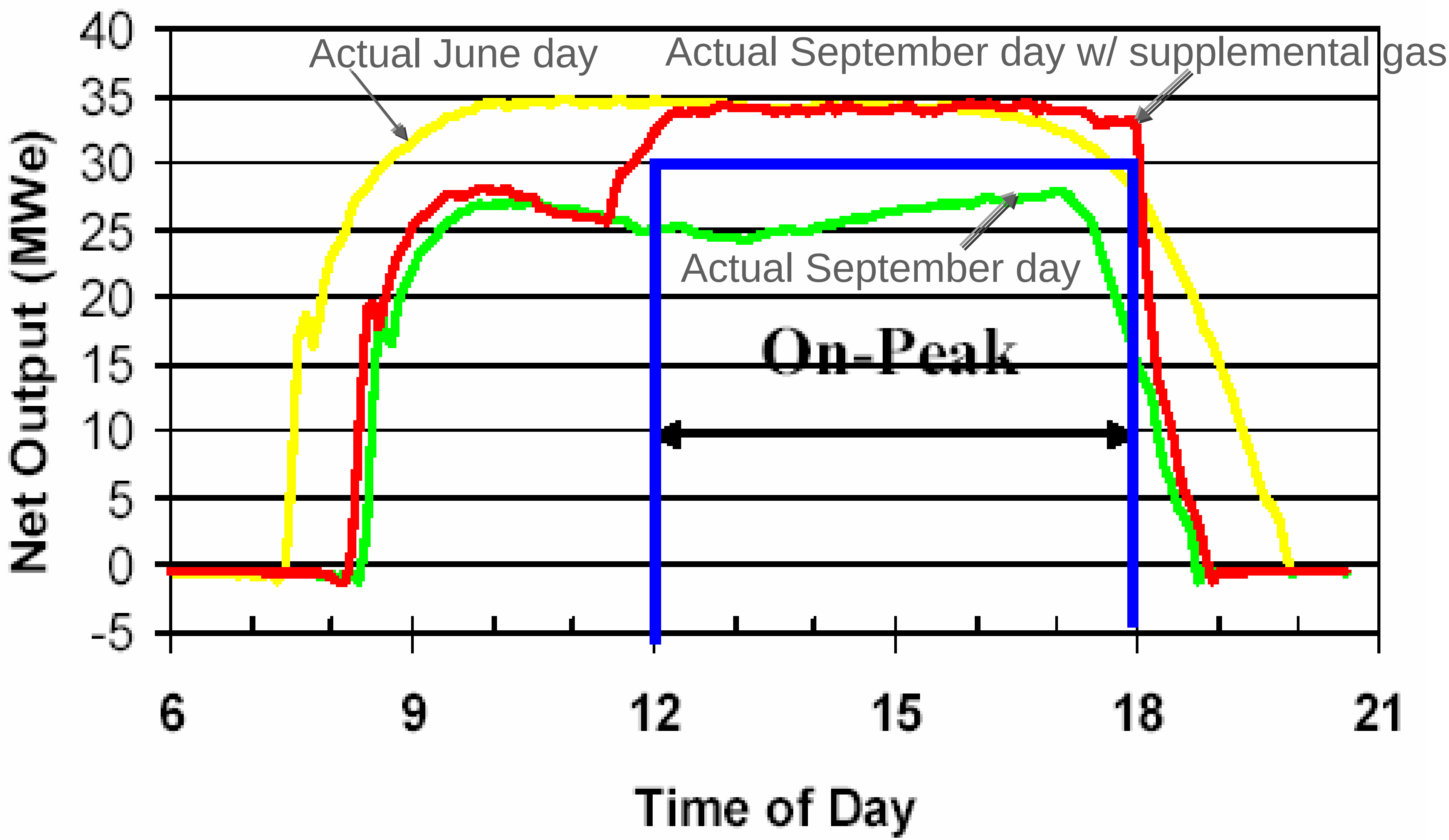
Operation: Mirrored dish focuses sunlight on a dish-mounted receiver. Heat engine at the focal point.

Key Advantage: Prototypes built and in operation for a number of years. Modular design (each dish is a complete plant).

Key Challenge: Dish requires smaller size units. Scaling design to manufacture in volume, maintenance due to many small engines (one per dish), heat engine working fluid challenges.

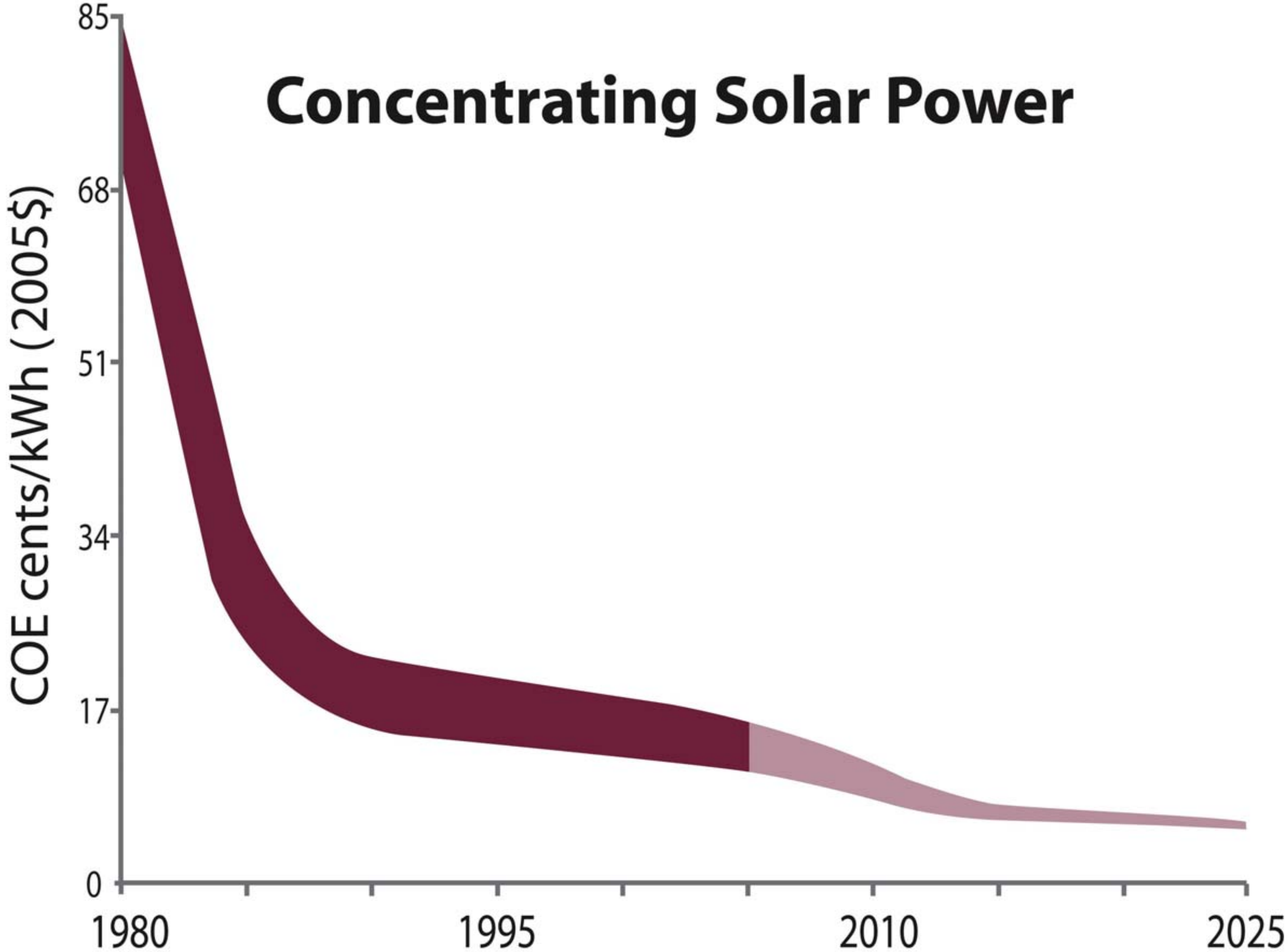
Solar Thermal: Portfolio Fit; Dispatchability Optio

olar thermal can add storage or gas/biofuel cofiring to become dispatchabl



Solar Energy Cost Trends

Levelized cost of energy in constant 2005$[1]



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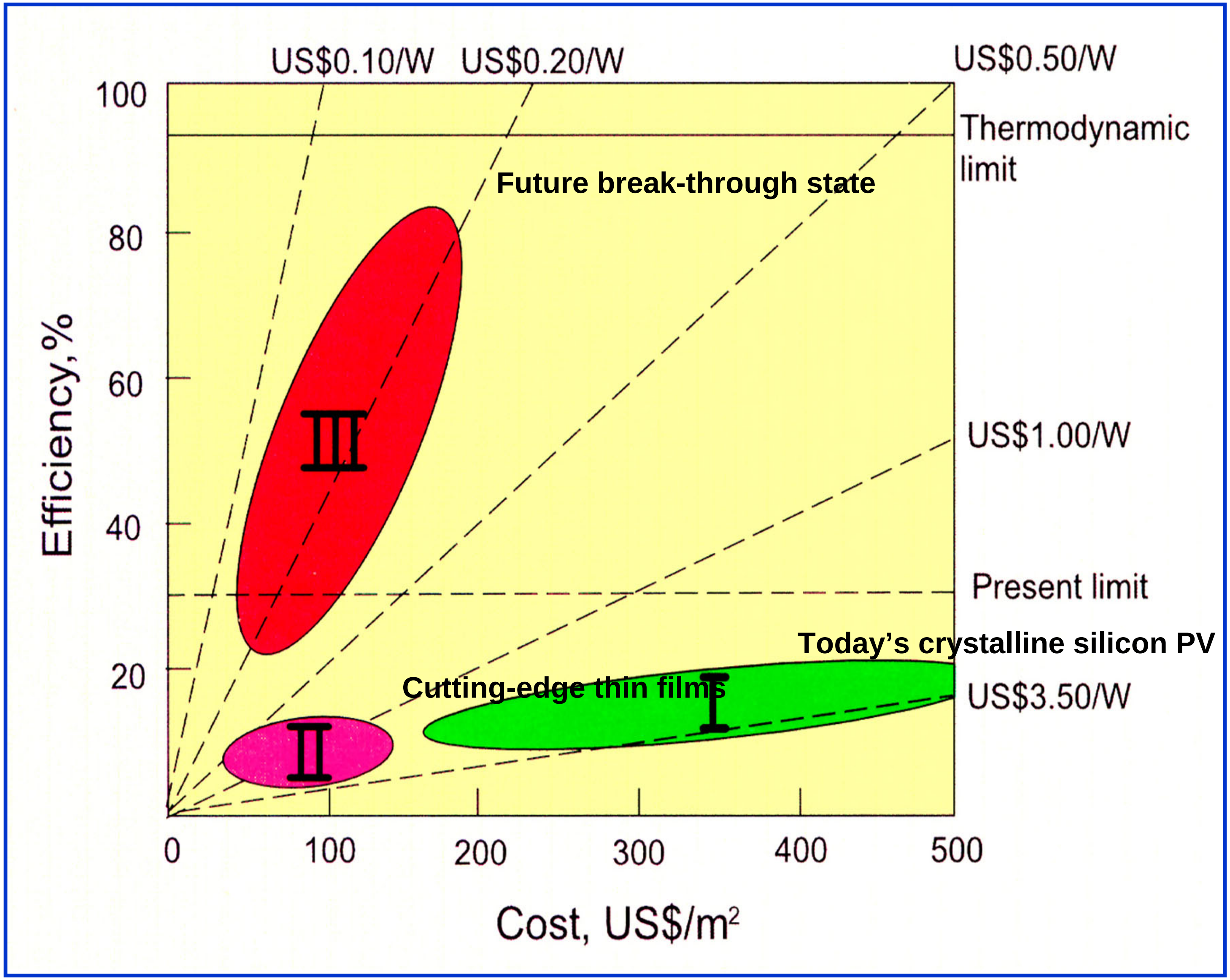
Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

Cost/Efficiency of Photovoltaic Technology



Source: N. Lewis, California Institute of Technology

PV Cell Efficiency

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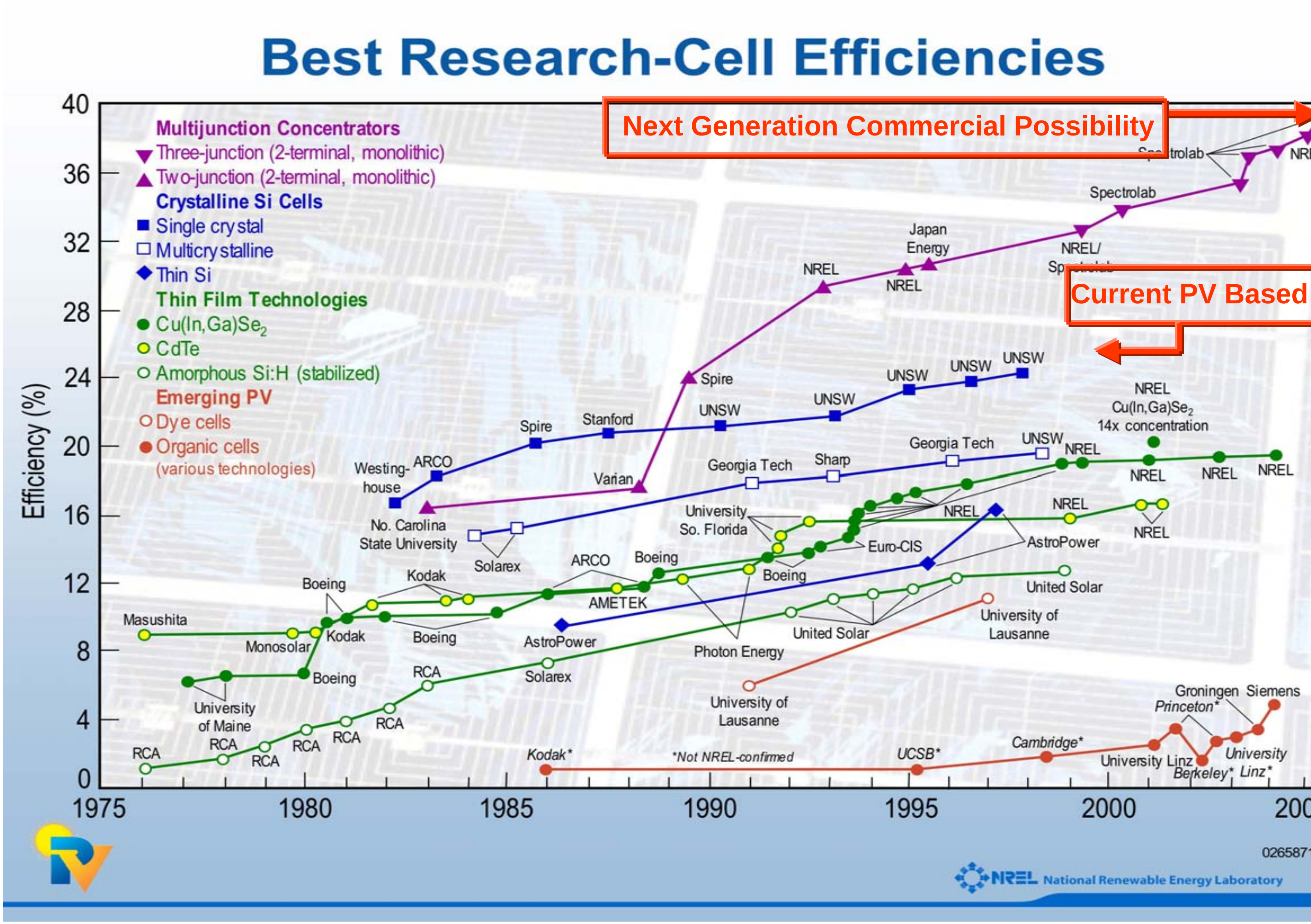
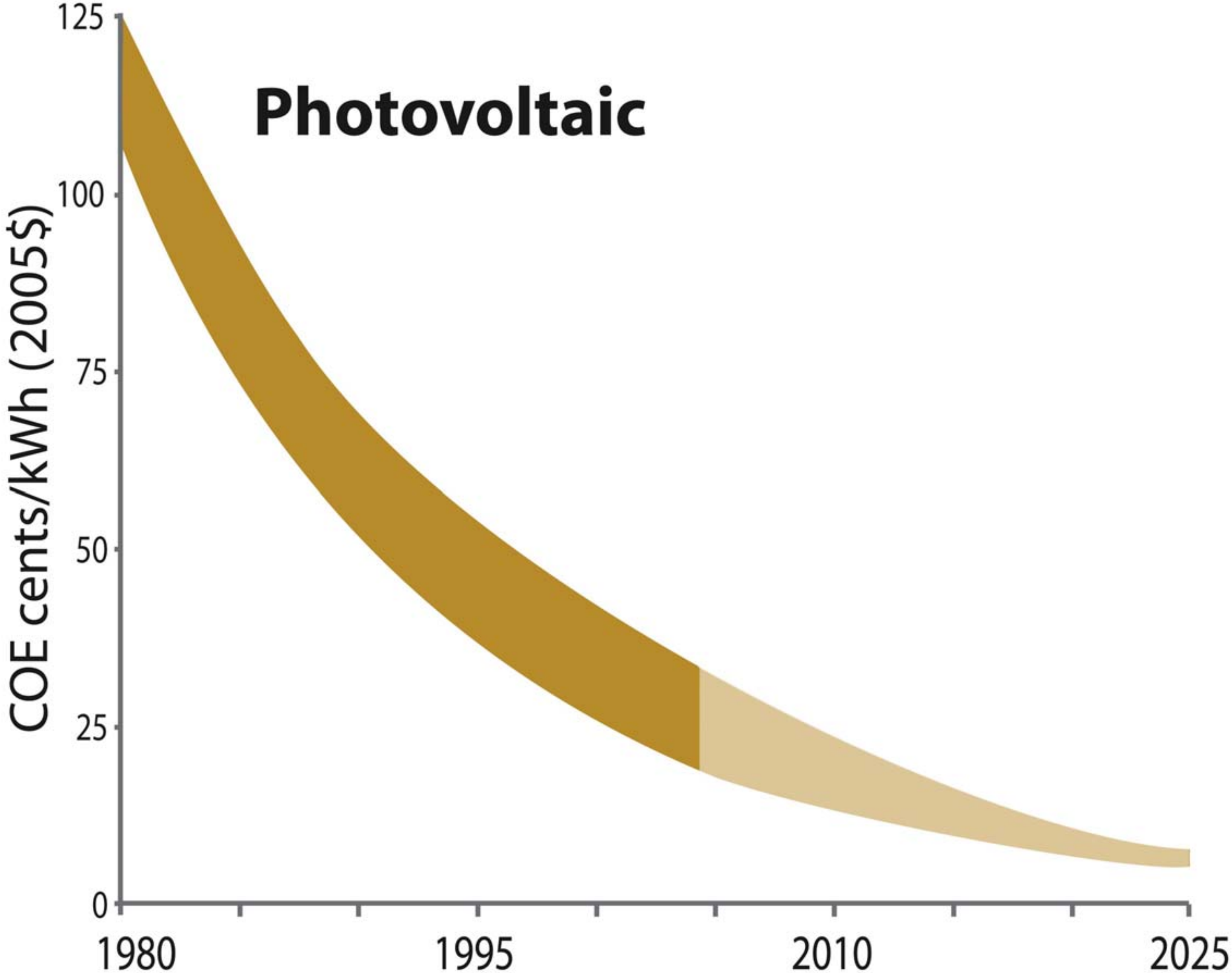


Source: K. Zweibel PV-PAST THE TIPPING POINT Presentation at NREL 08/31/2005

Solar Energy Cost Trends

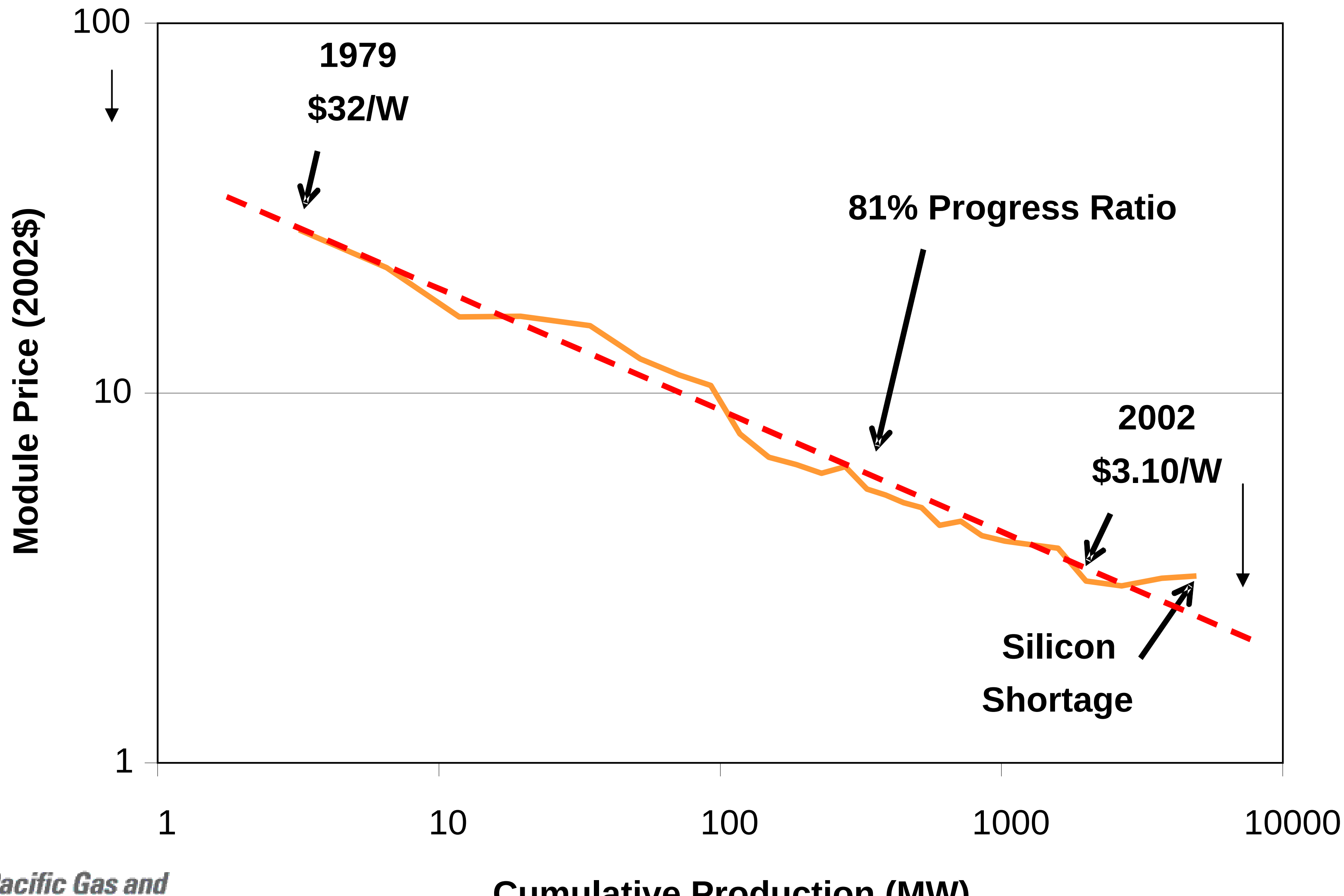
Levelized cost of energy in constant 2005$[1]



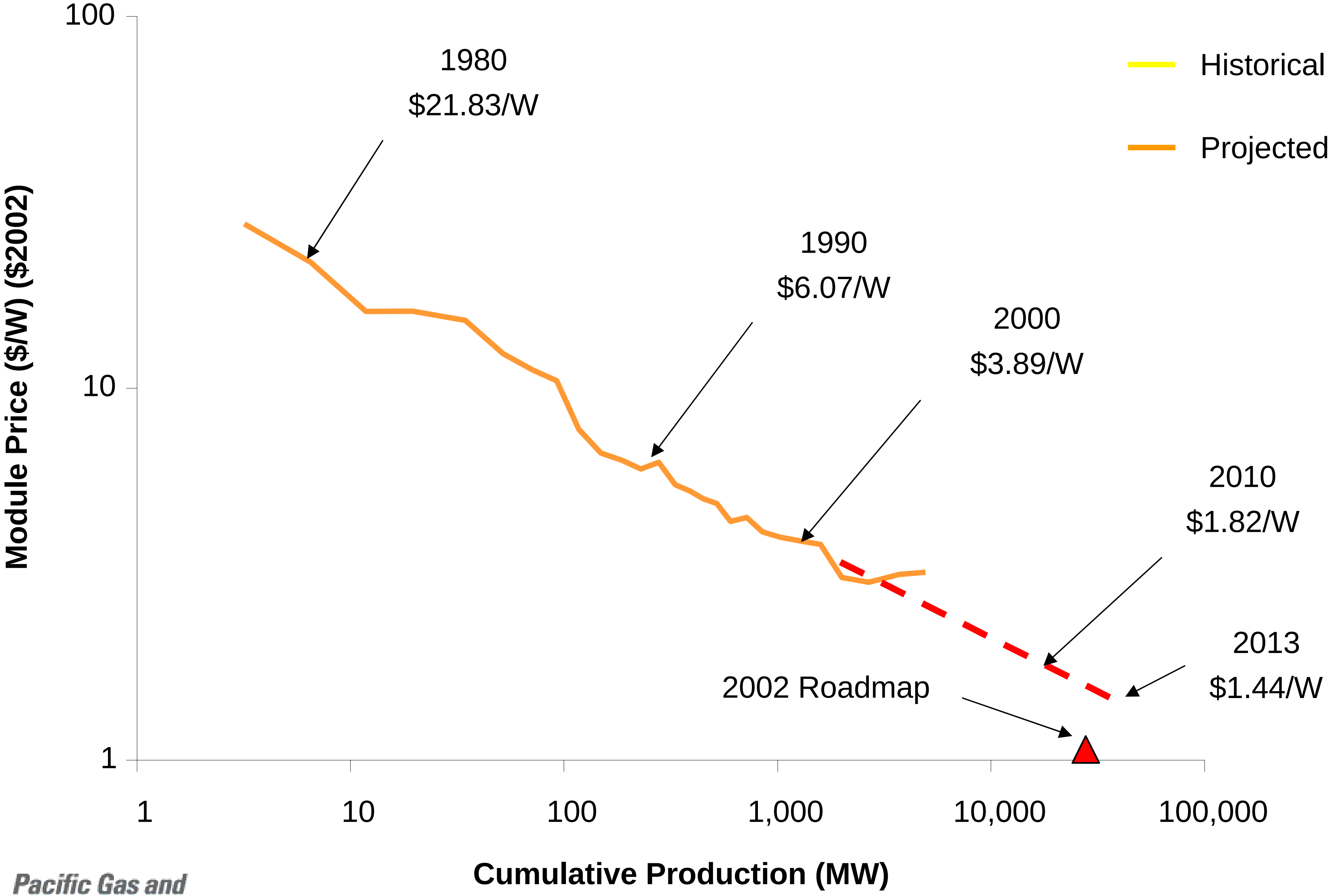
Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

olar Price Learning Curve

olar Panel Cost Drops by 19% with Each Doubling in Manufacturing Capac



Retail Rate Parity Projected in Less Than 10 Years

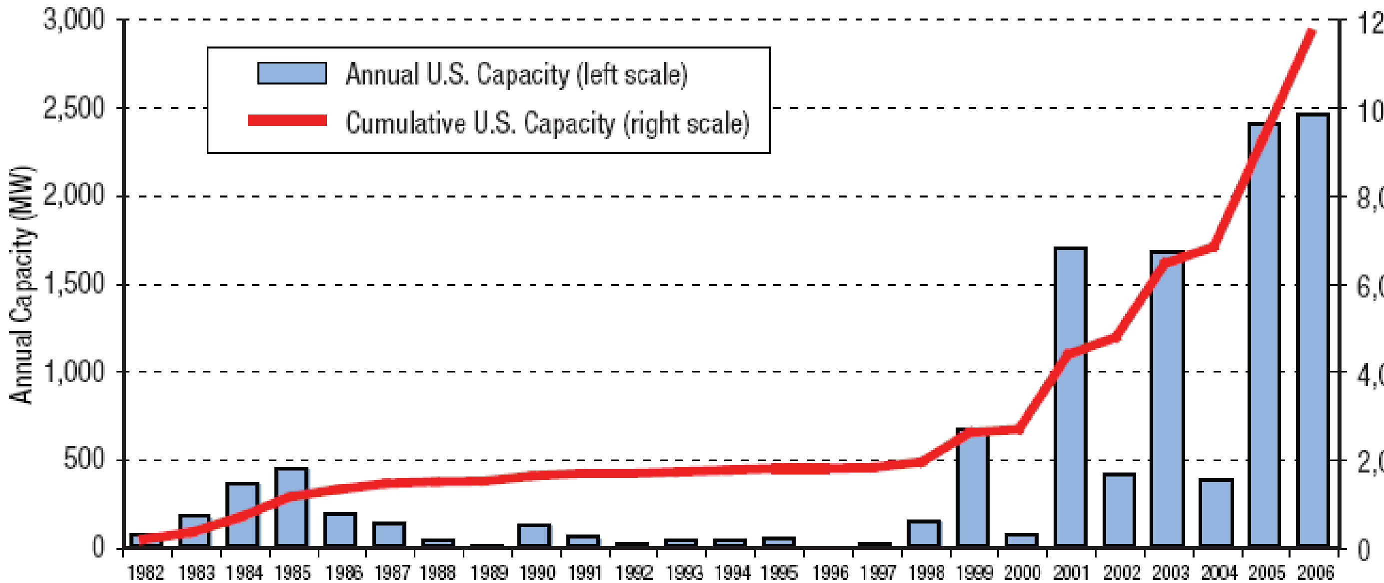


Other PV Cost Issues

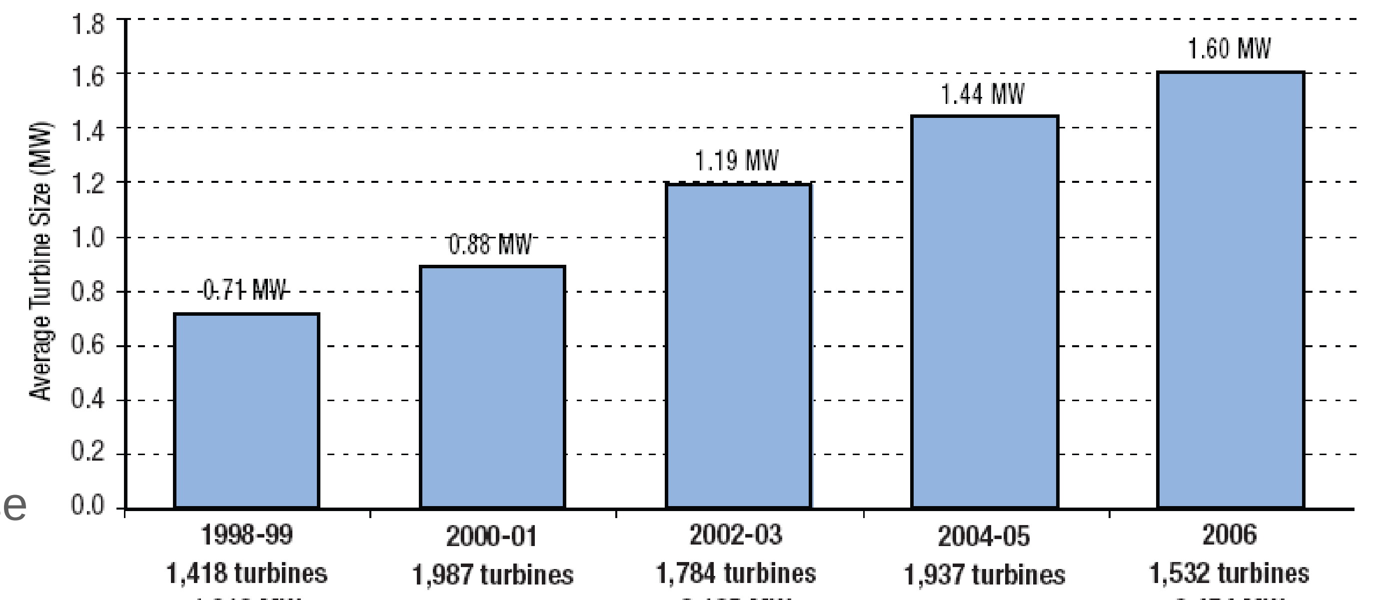
- Today's approximate installed PV cost breakdown: $9/W
  - Cell: $3/W
  - Assembly: $2/W
  - Inverter: $1/W
  - Installation: $3/W
- Inverter longevity also needs to be addressed
- Installation costs may be reduced using Building Integrated Photovoltaics
  - BIPV reduces incremental labor cost by being part of the original construction

U.S. Wind Power Trends

Growth of wind in strong as long as tax credits in effect.



Turbine sizes continue to increase.



Source: AWEA/GEC database

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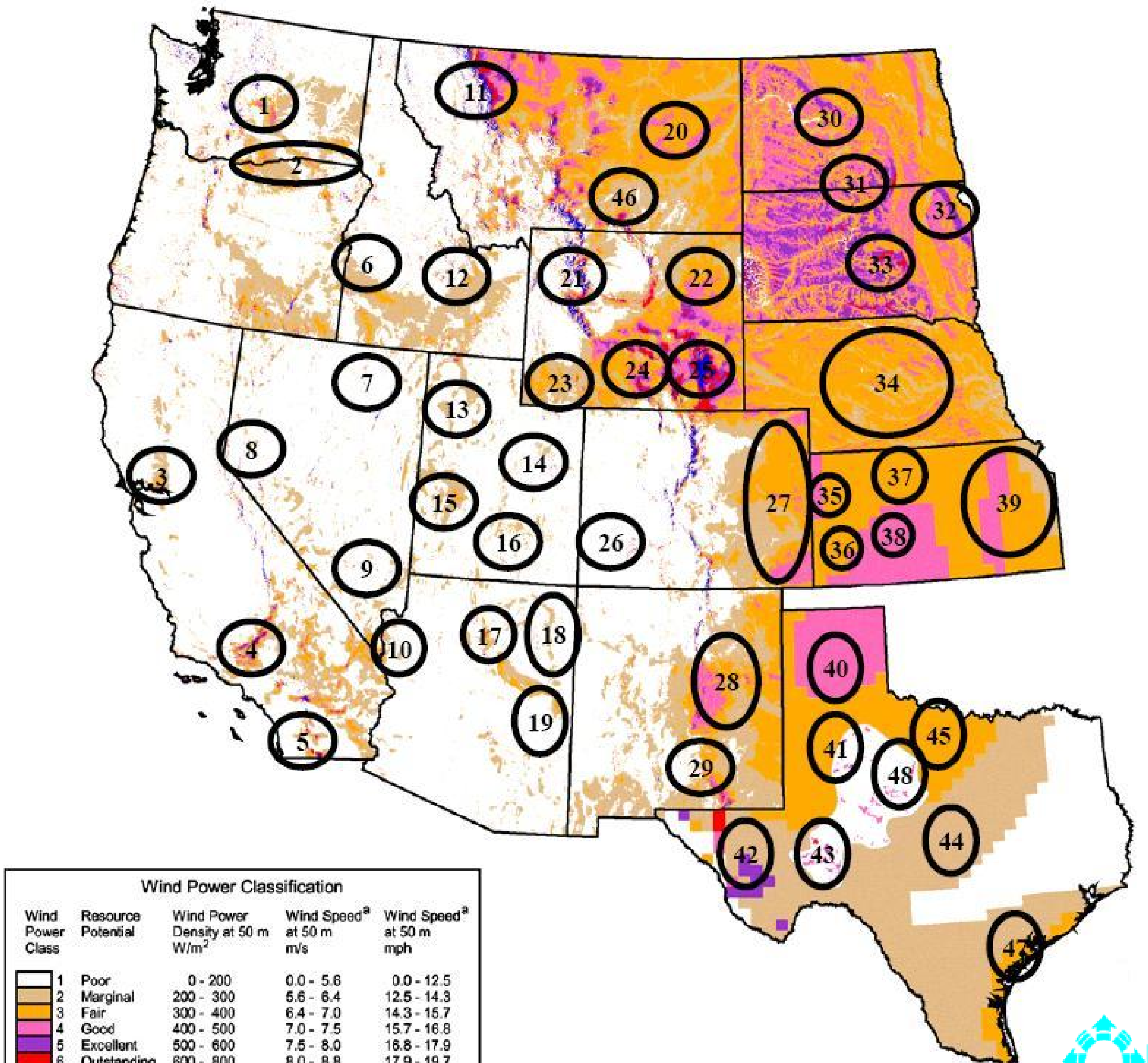
Western U.S. Onshore Wind Resources

- 55,000 MW of 2015 potential identified by Western Governors Association task force.
- More than 15,000 MW already applied to the CAISO for transmission, including from areas not identified by WGA.



Transmission Needed for Utility-Scale Renewables

- Utility-scale renewable resources and loads are negatively correlated
- Connecting renewables to the grid is a growing issue
  - Local network reinforcements
  - New rights of way => NIMBY problems
- Transmission congestion is resource and area specific, e.g., California South-to-North constraints
  - Adequate daytime, on-peak capacity to bring resources north
    - Solar not constrained
  - Inadequate night-time, off-peak capacity to bring resources north
    - “Baseload” resources (e.g., wind, geothermal, and biomass) constrained
- Classic “chicken or egg” problem in matching transmission to renewables should be solved by new California Renewable Energy Transmission Initiative.

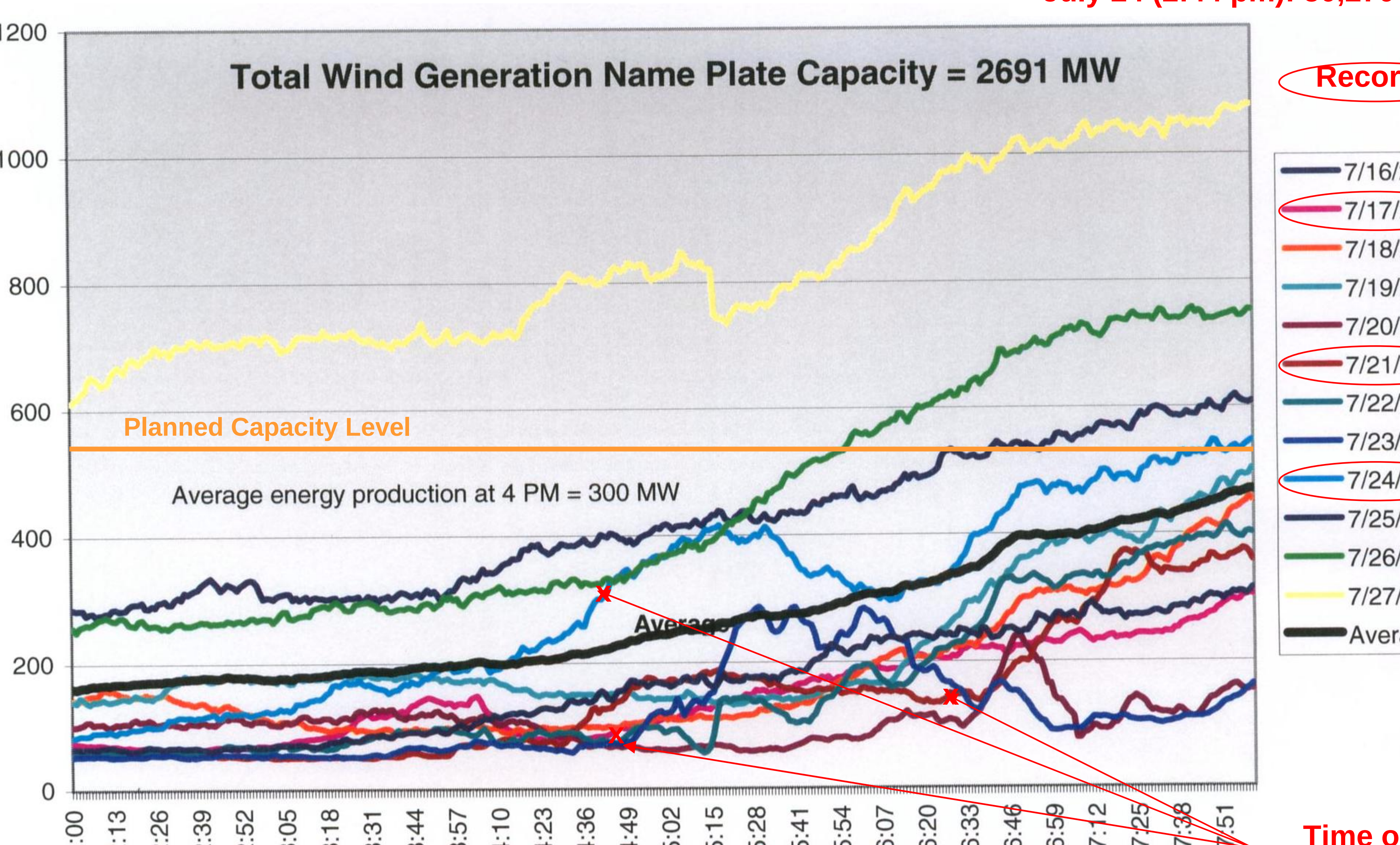
uly 2006 Heat Wave – Peak Hours
Vind Generation Energy Production

New Records

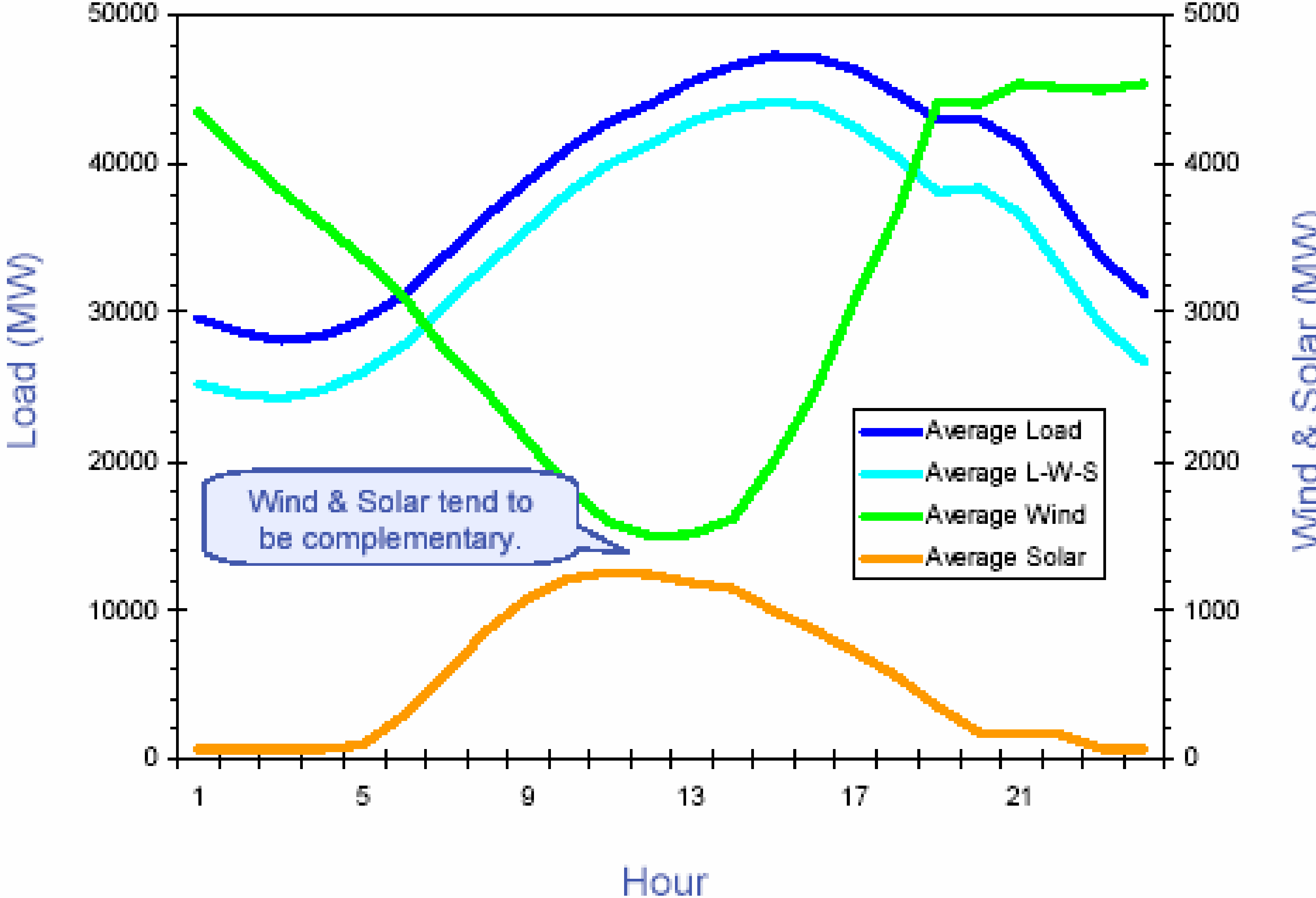
July 17 (2:41 pm): 46,561

July 21 (4:28 pm): 49,036

July 24 (2:44 pm): 50,270

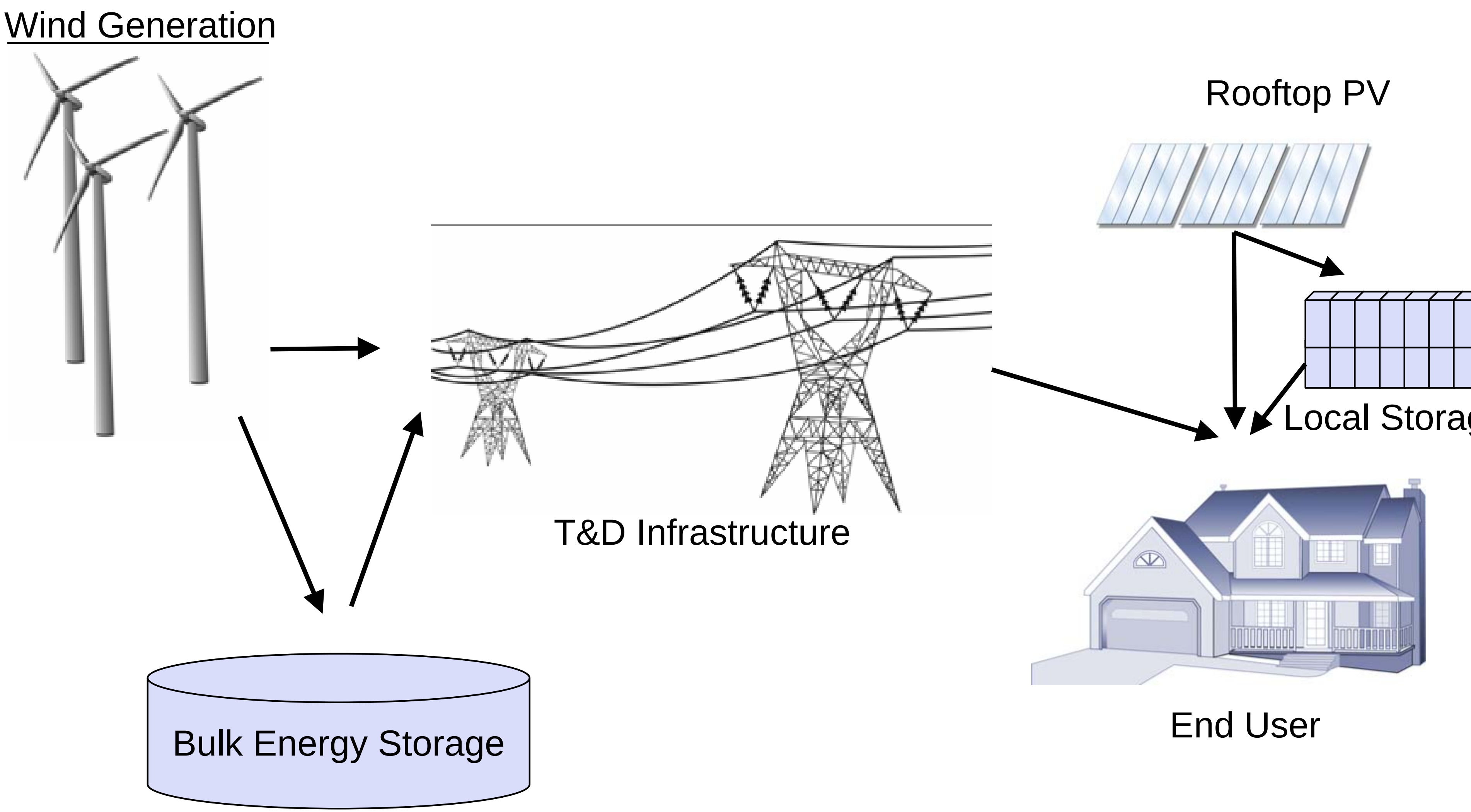


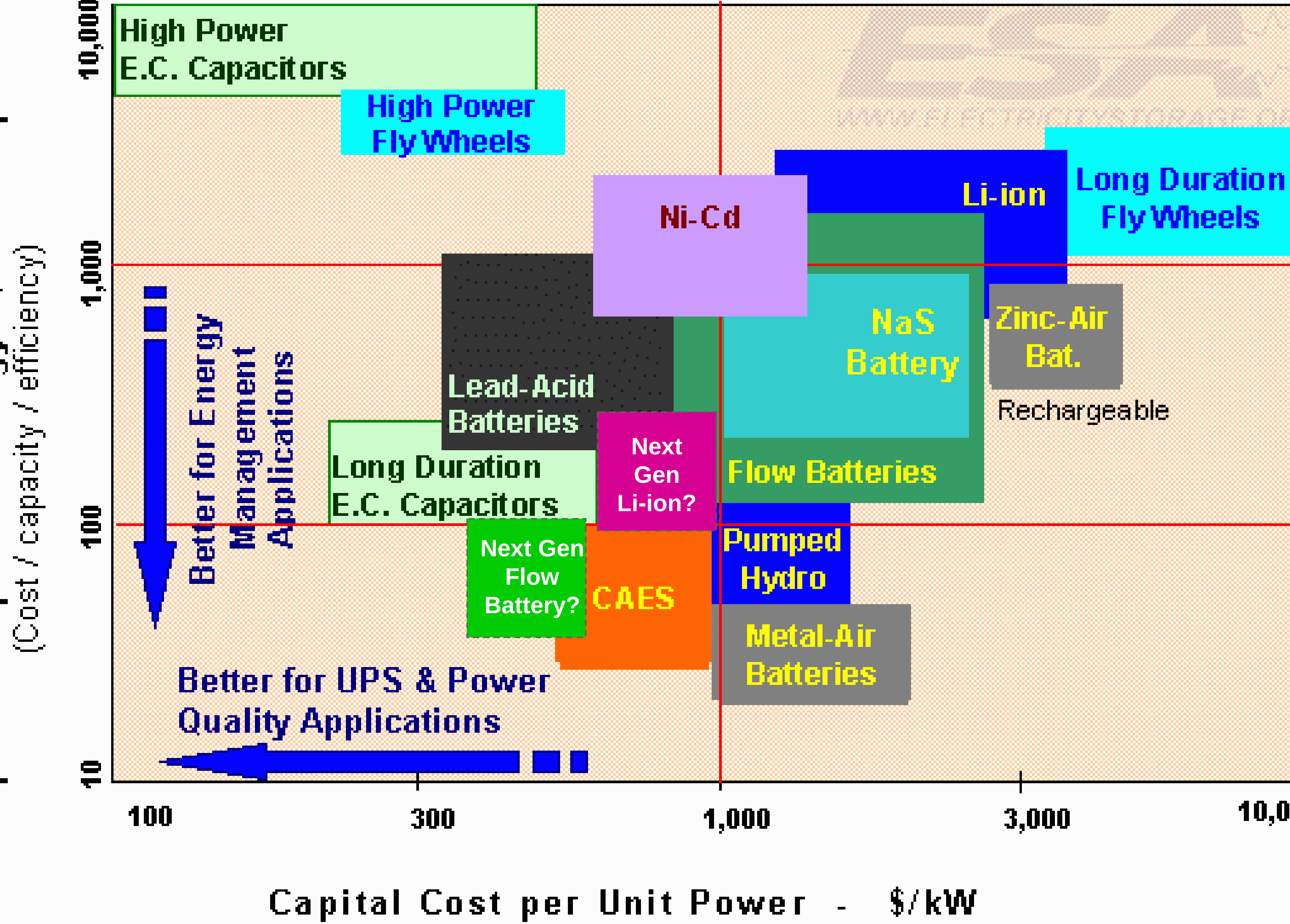
Resource Patterns



Temporal Pattern: July 2003 Average Day

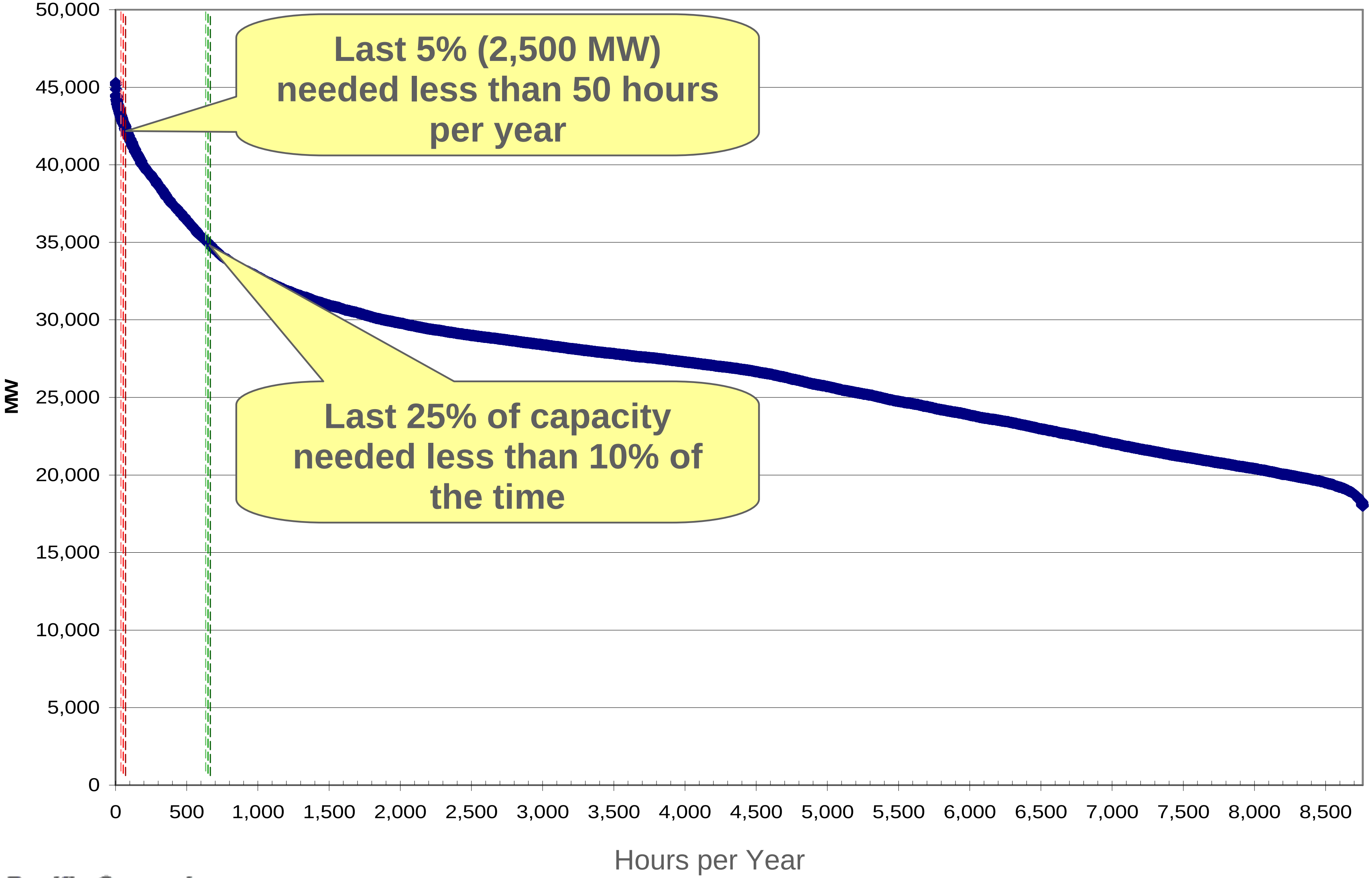
Energy Storage and Grid Integration



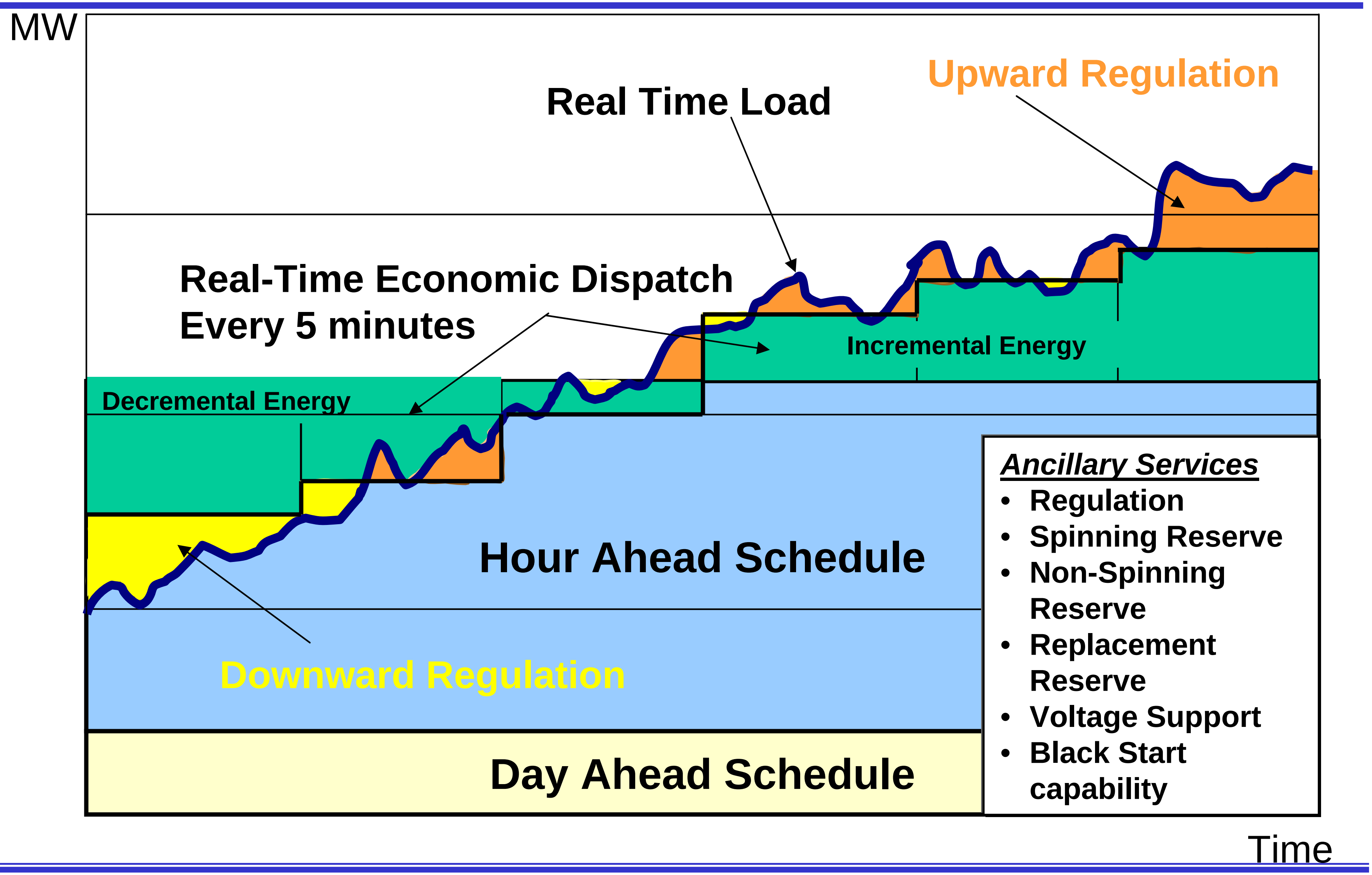


High Power E.C. Capacitors
High Power Fly Wheels
Li-ion
Long Duration Fly Wheels
Ni-Cd
NaS Battery
Zinc-Air Bat.
Rechargeable
Lead-Acid Batteries
Better for Energy Management Applications
Long Duration E.C. Capacitors
Next Gen Li-ion?
Flow Batteries
Next Gen Flow Battery?
CAES
Pumped Hydro
Metal-Air Batteries
Better for UPS & Power Quality Applications
(Cost / capacity / efficiency)
10,000
1,000
100
10
100
300
1,000
3,000
10,0
Capital Cost per Unit Power - $/kW

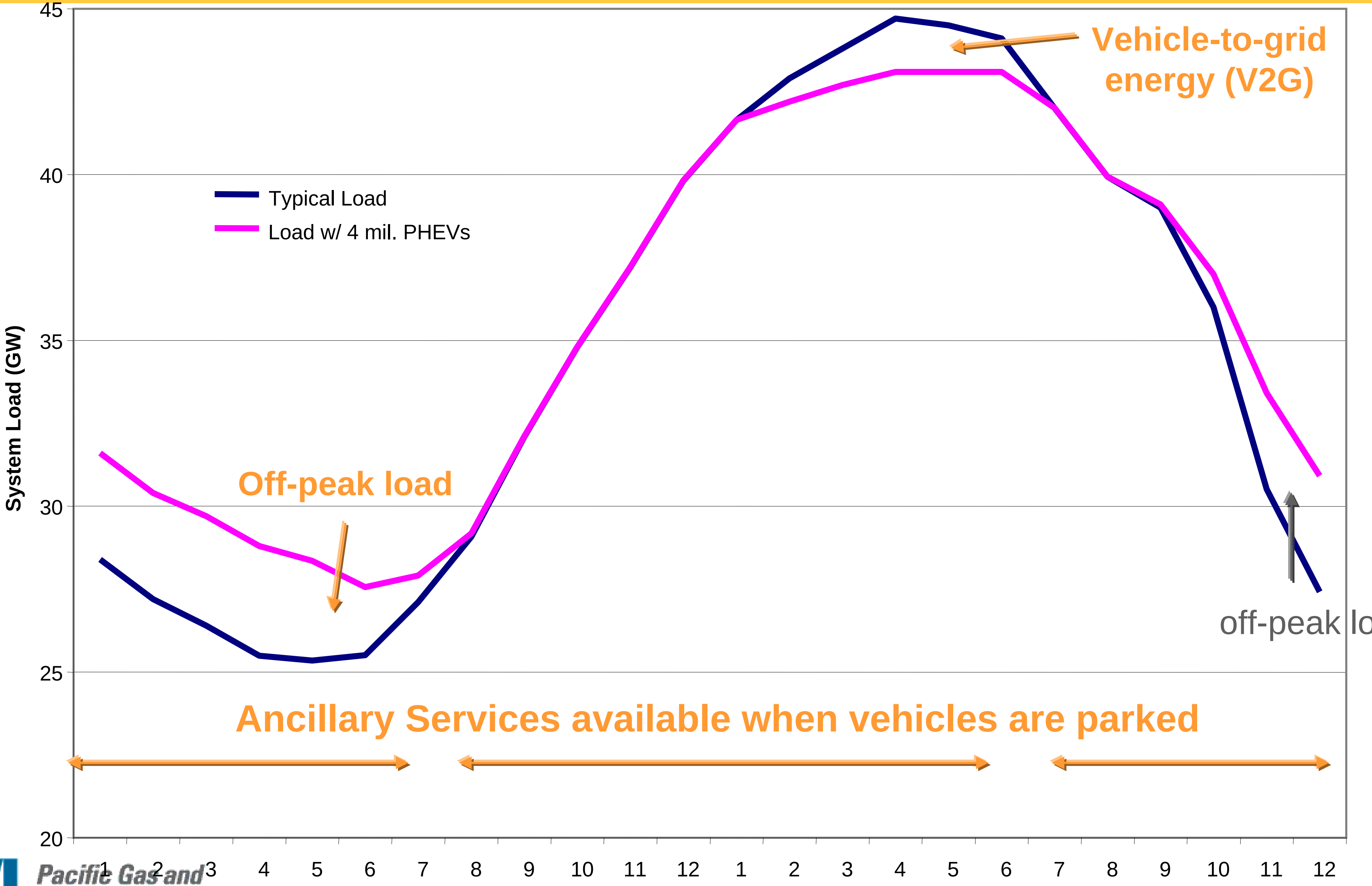
Electric Load Duration Curve Also Shows Value of Storage



Balancing Function - Area Control

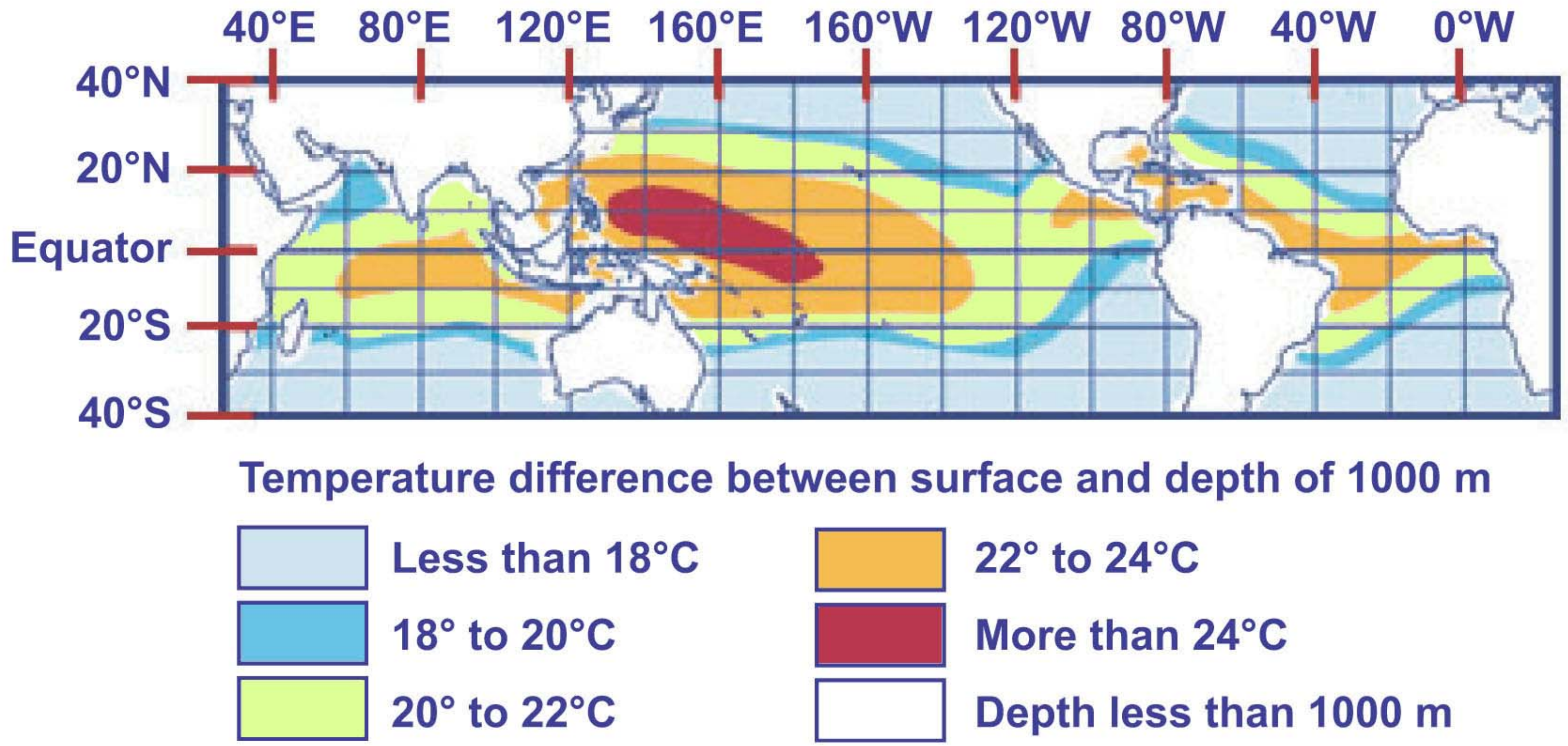


lug Hybrid Electric Vehicles Complement Renewables

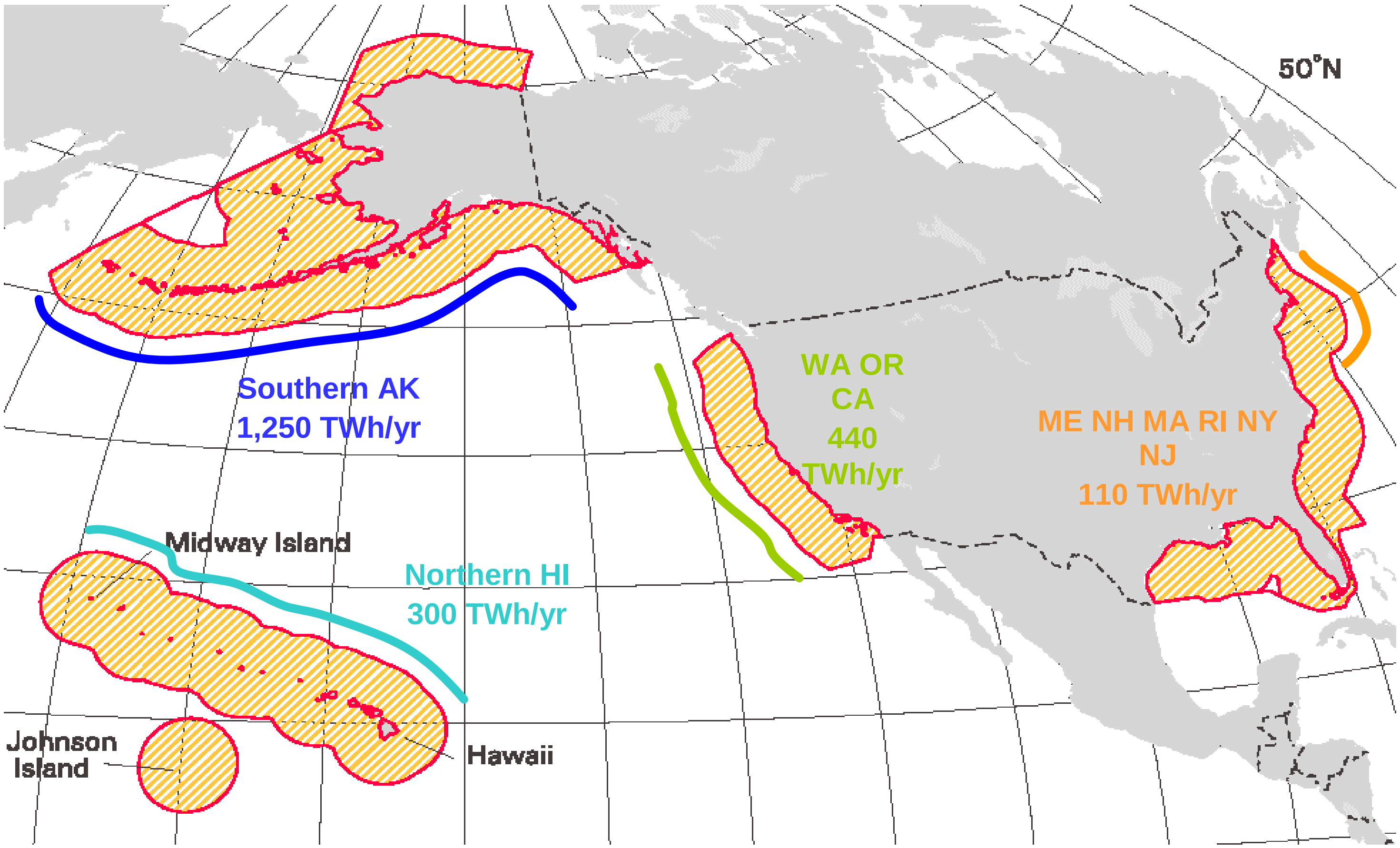


Global Ocean Thermal Gradient

Temperature difference between warm surface water and cold deep water must be >20°C (36°F) for OTEC system to produce significant power



Wave and Tidal Resource



Total Wave Energy Resource Easy to Calculate – Total Tidal Resource Difficult to Calculate

Total US flux into all regions with avg. wave power density >10 kW/m is ~2,100 TWh/yr

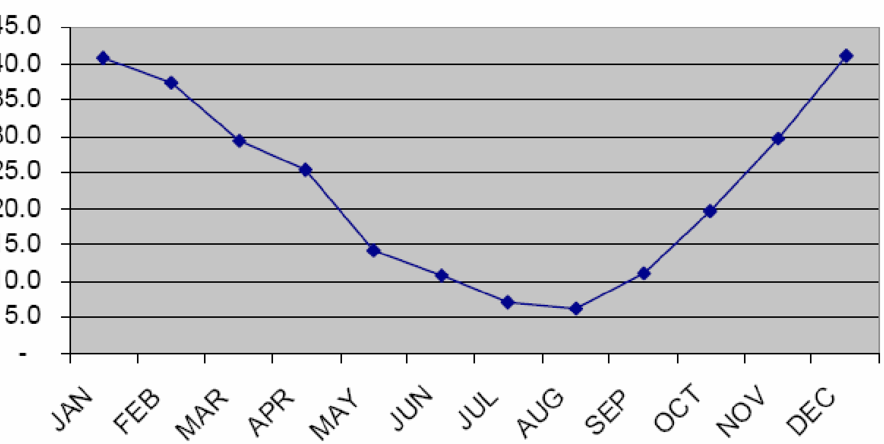
Harnessing 20% of offshore wave energy resource at 50% efficiency would be comparable to all US conventional hydro generation in 2003.

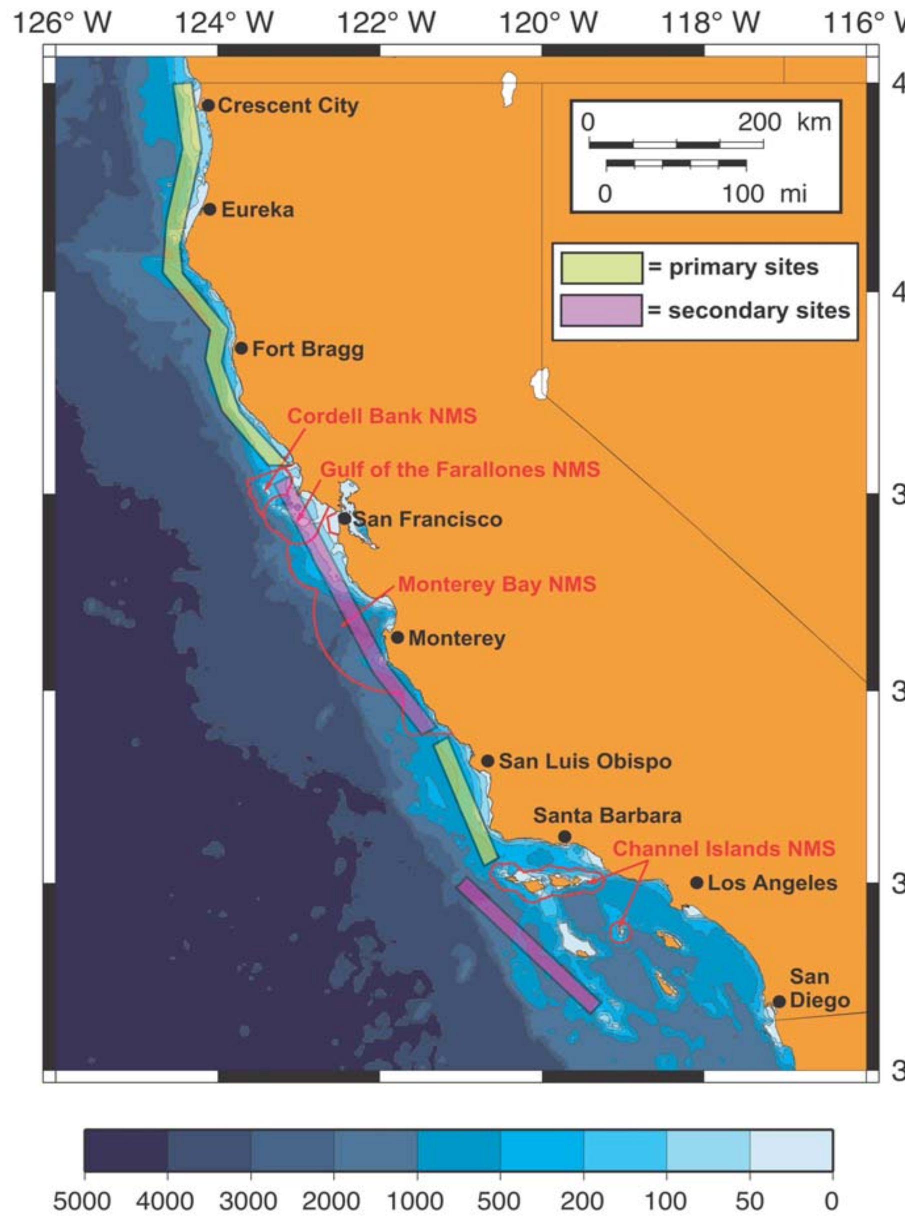
Potential California Wave Power Generation

Summary of 2003 CEC wave study:

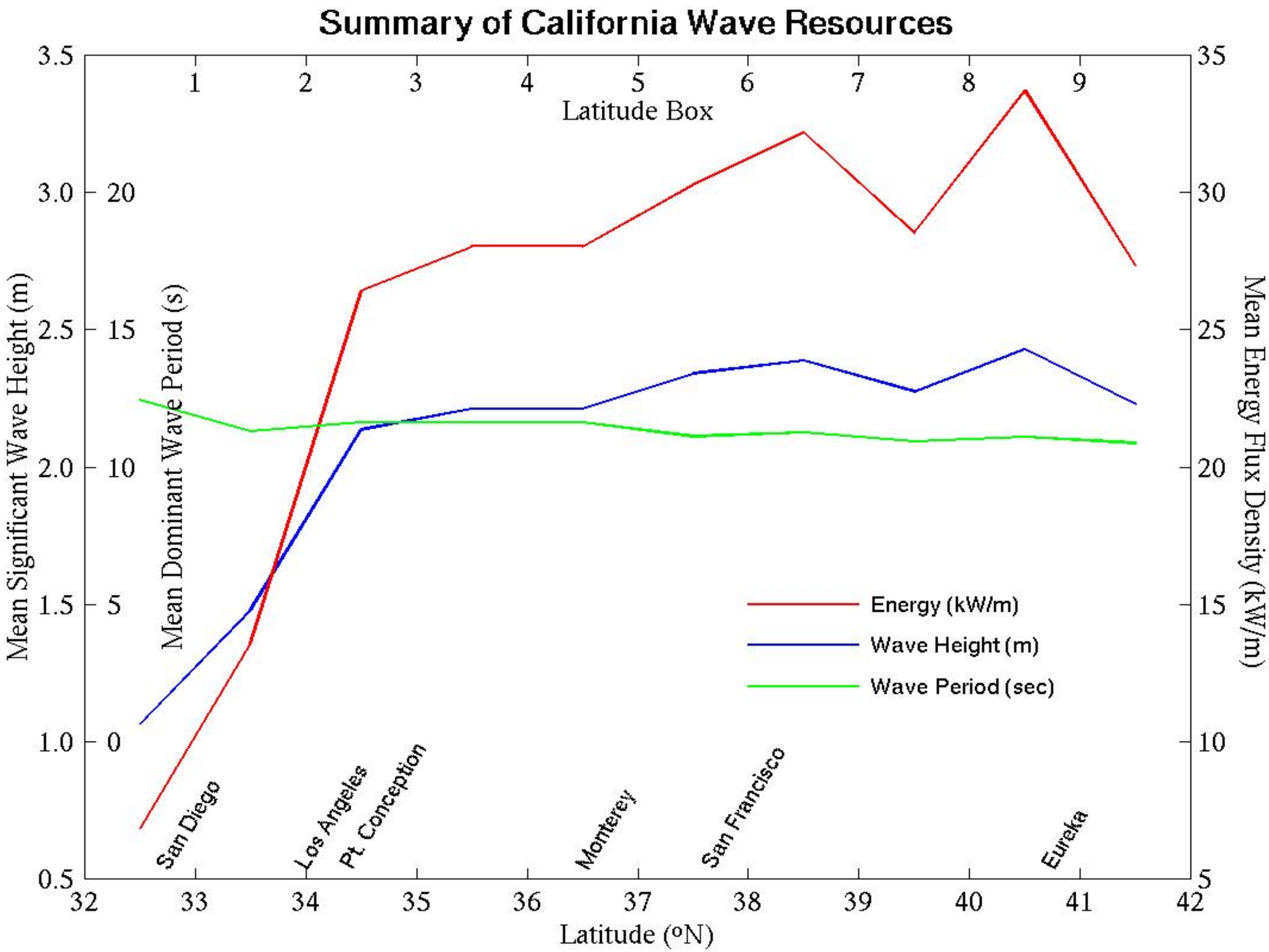
– "Nearshore wave power sites could provide California with an additional 8000 MW capacity…long-term deep-water potential can exceed the nearshore potential by a factor of 5-10, assuming it proves technically and economically feasible (expected within 10 years)."

Wave energy is highest in the winter





Wave Energy Density Varies Widely Off Coastline at Point Conception from N-S



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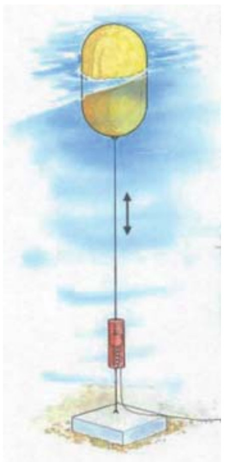
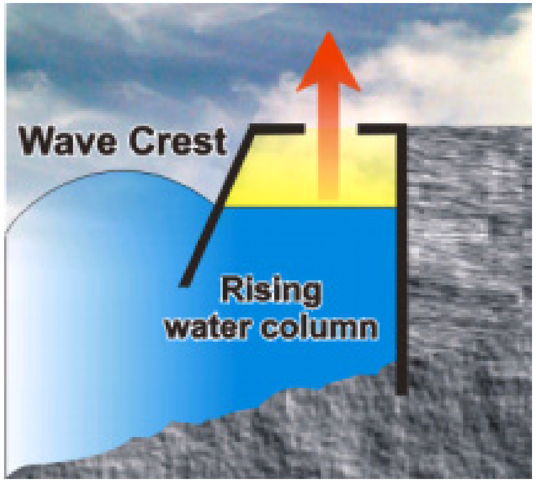
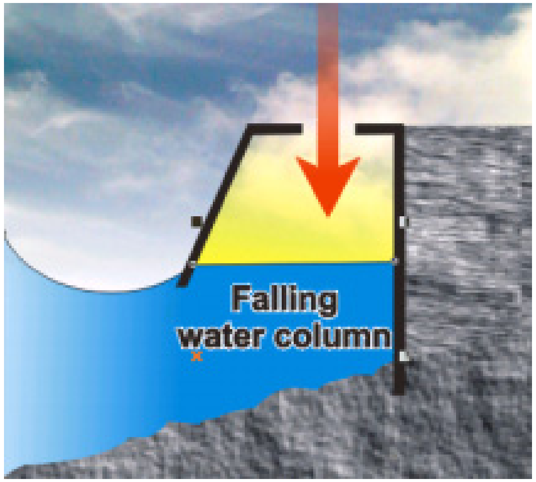
4 Primary Types of Wave Energy Conversion

Point Absorber

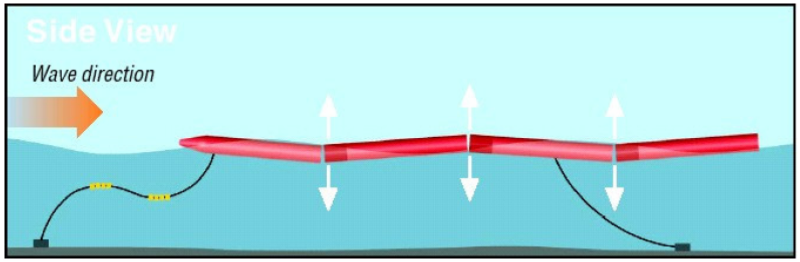


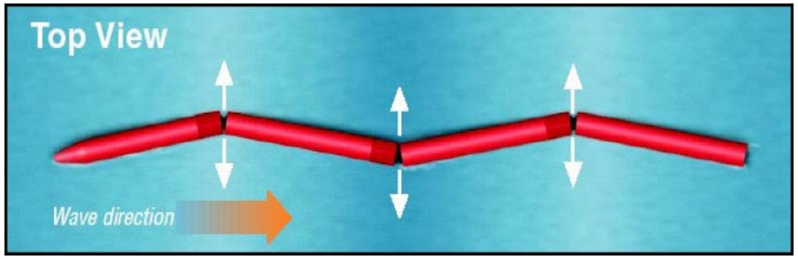
Terminator- Oscillating Water Column



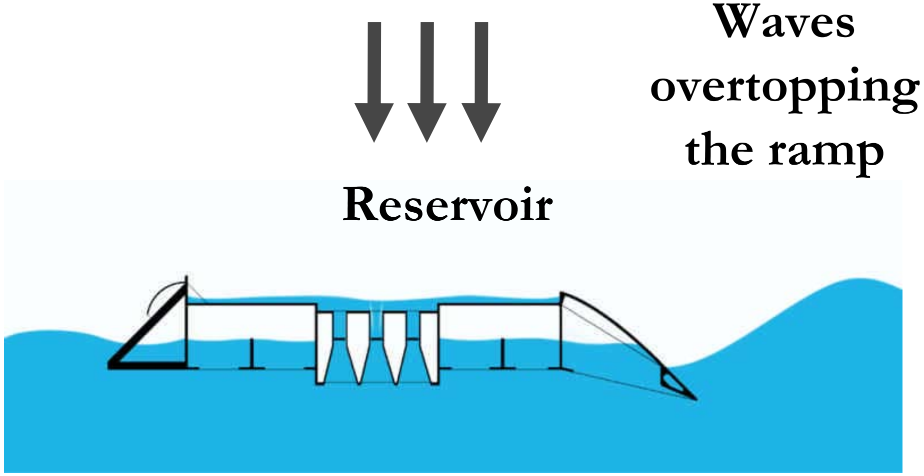


Attenuator





Overtopping



Examples of Wave Energy Devices (WECs)

Point Absorber (AquaEnergy AquaBuOY)

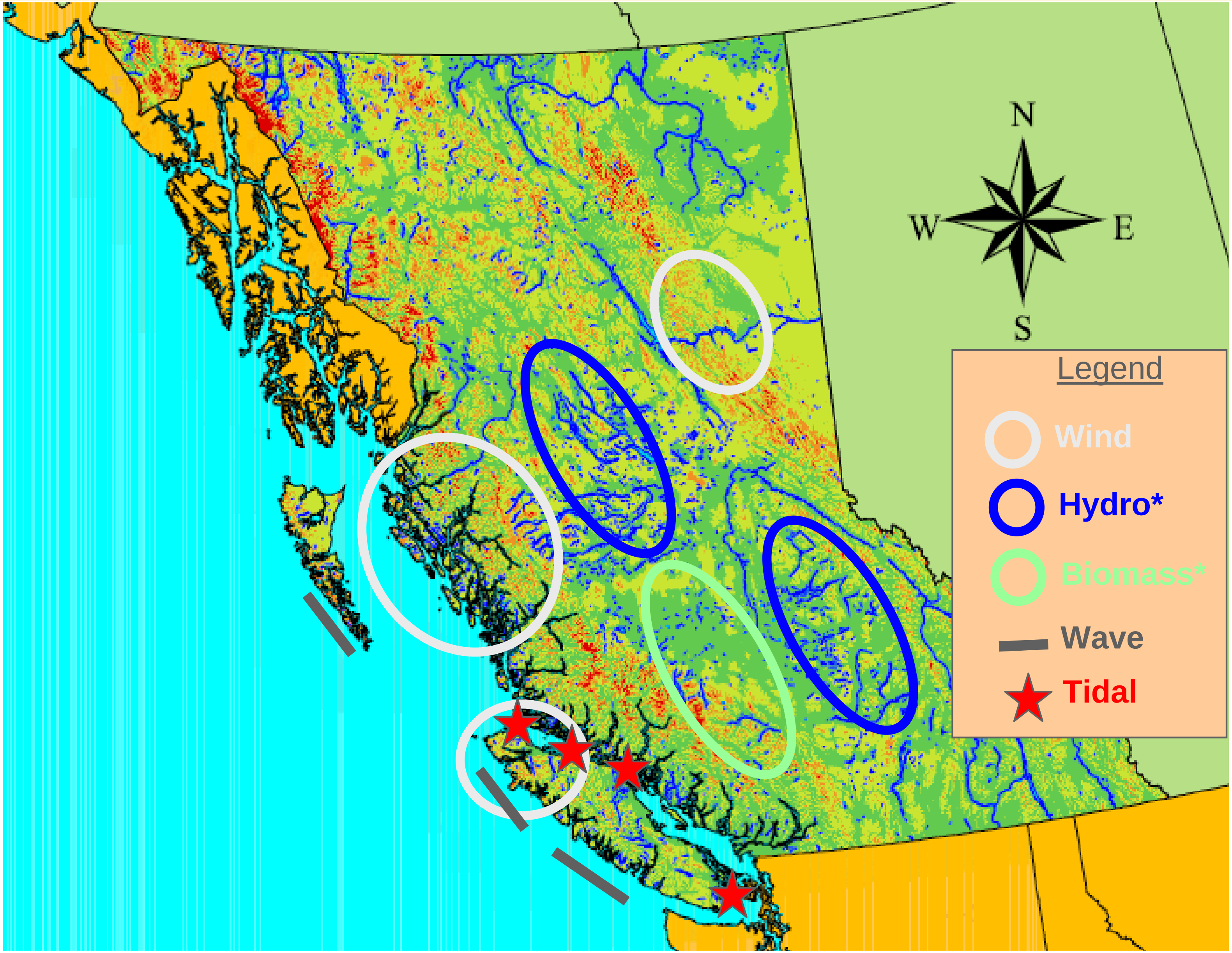
Terminator (Energetech Oscillating Water Column)

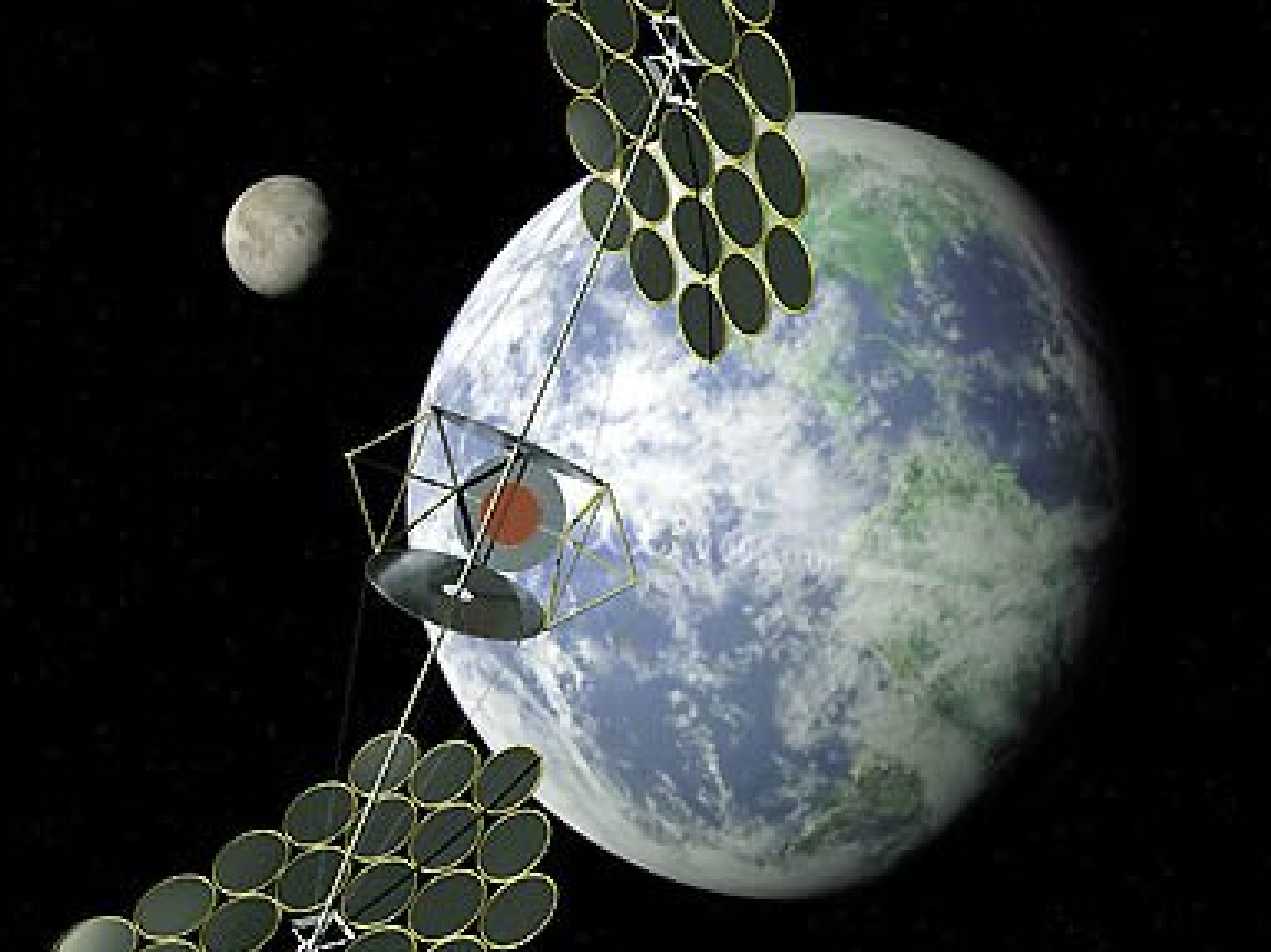
Attenuator (OPD Pelamis)

Overtopping (Wave Dragon)

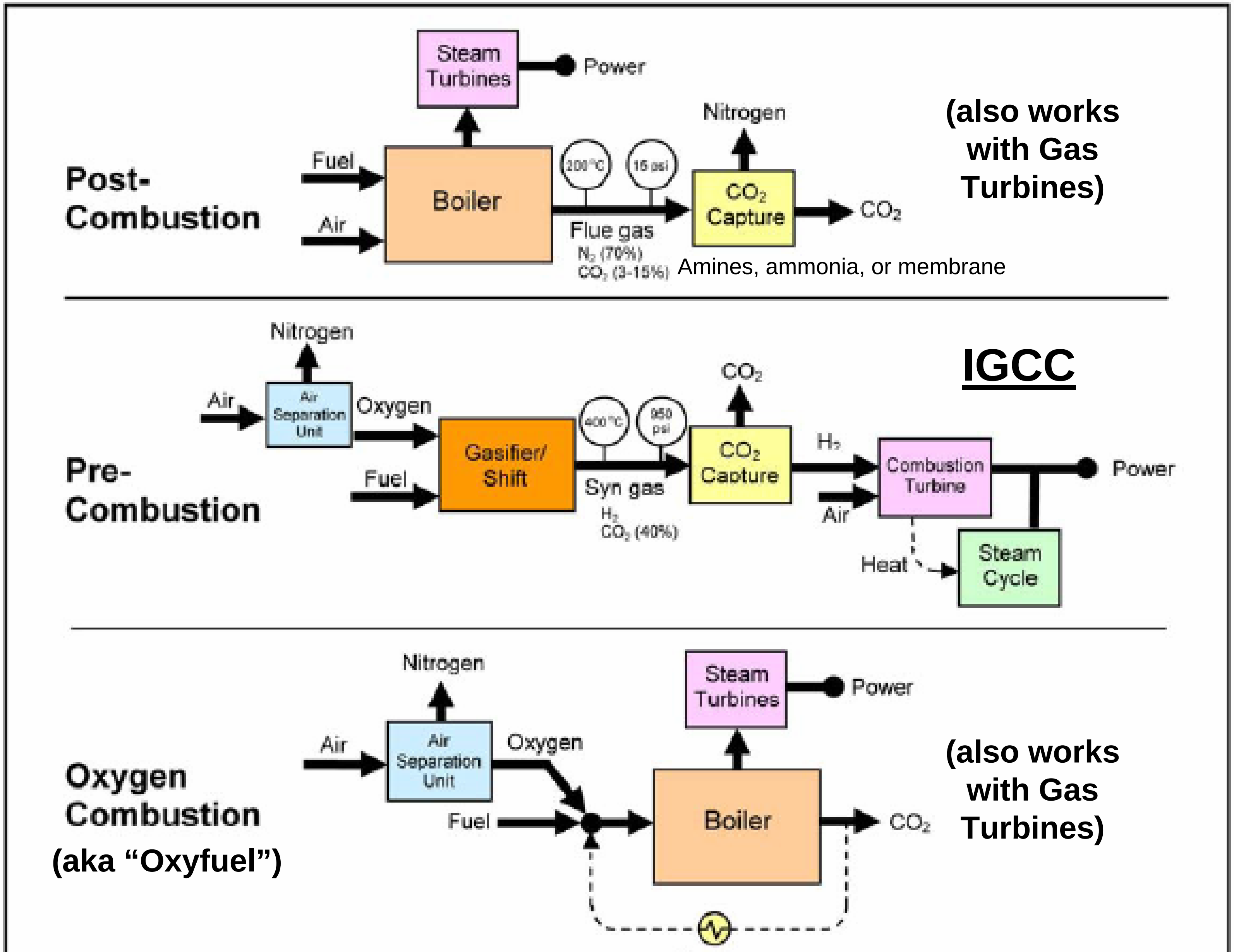
EPRI

British Columbia Renewable Resources



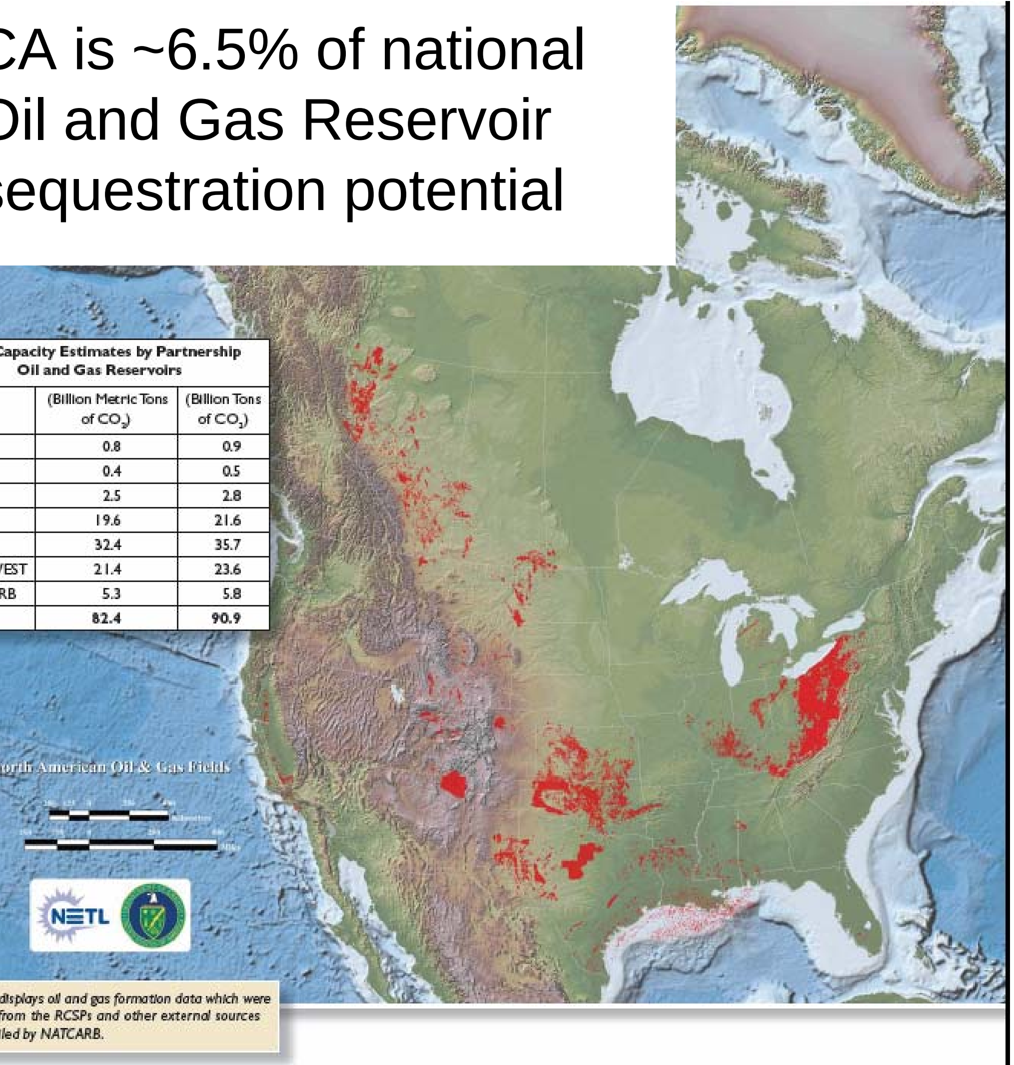


Three Established Means of Carbon Capture



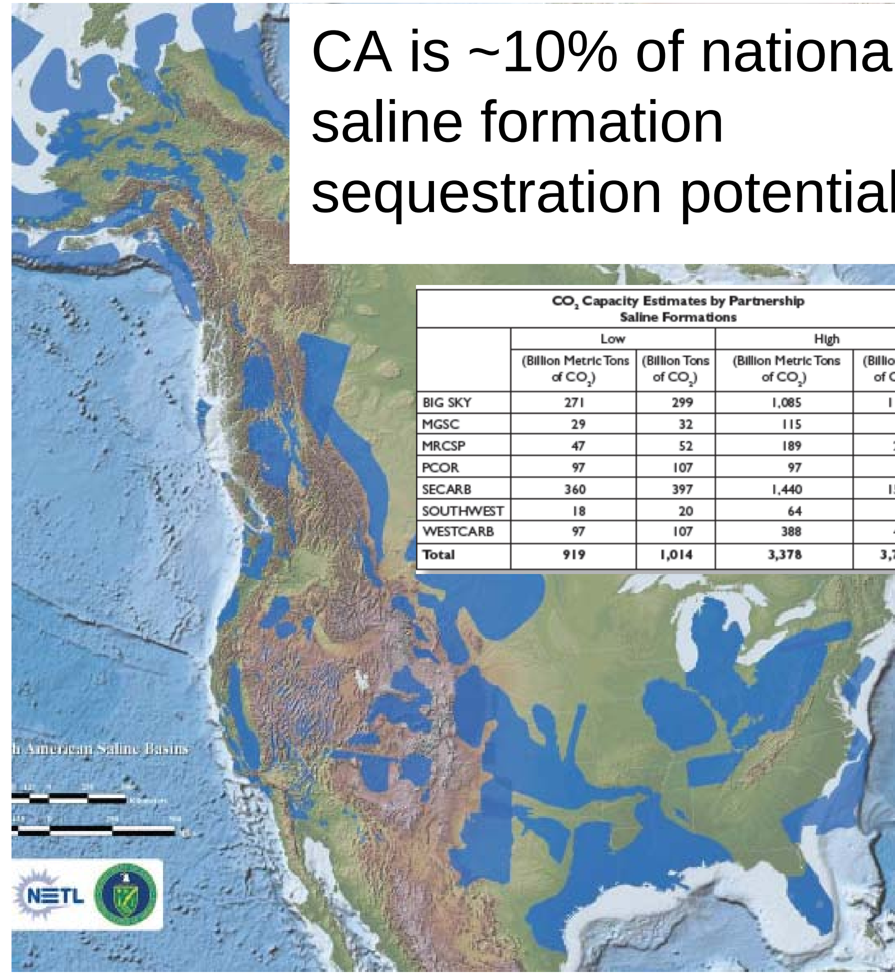
Sequestration Potential: Oil & Gas Reservoirs and Saline Formations

CA is ~6.5% of national Oil and Gas Reservoir sequestration potential



apacity Estimates by Partnership Oil and Gas Reservoirs		
	(Billion Metric Tons of CO_2)	(Billion Tons of CO_2)
	0.8	0.9
	0.4	0.5
	2.5	2.8
	19.6	21.6
	32.4	35.7
VEST	21.4	23.6
RB	5.3	5.8
	82.4	90.9

CA is ~10% of nationa saline formation sequestration potential



CO_2 Capacity Estimates by Partnership Saline Formations				
	Low		High	
	(Billion Metric Tons of CO_2)	(Billion Tons of CO_2)	(Billion Metric Tons of CO_2)	(Billio of C
BIG SKY	271	299	1,085	1
MGSC	29	32	115	
MRCSP	47	52	189	
PCOR	97	107	97	
SECARB	360	397	1,440	1
SOUTHWEST	18	20	64	
WESTCARB	97	107	388	
Total	**919**	**1,014**	**3,378**	**3,7**